An opensource multifidelity framework for Aircraft Design:

Modeling issues and illustrative examples

Prof J. Morlier with the help of C. Bruni,

J. Mas Colomer etc…

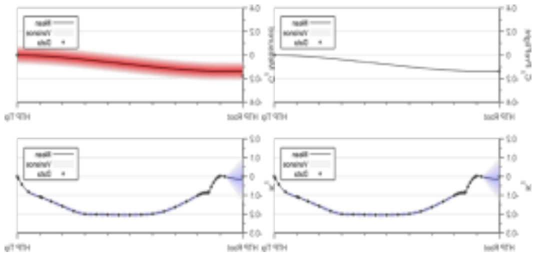
Workshop Recherche CEDAR
Airbus-ISAE Supaéro

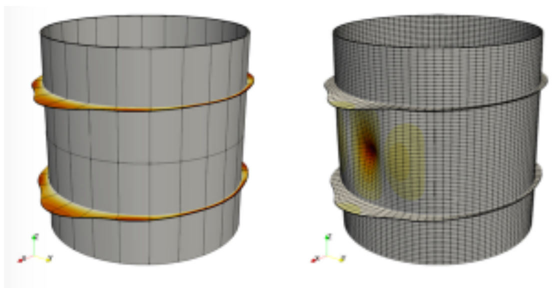
Isae
Institut Supérieur de l'Aéronautique et de l'Espace
SUPAERO

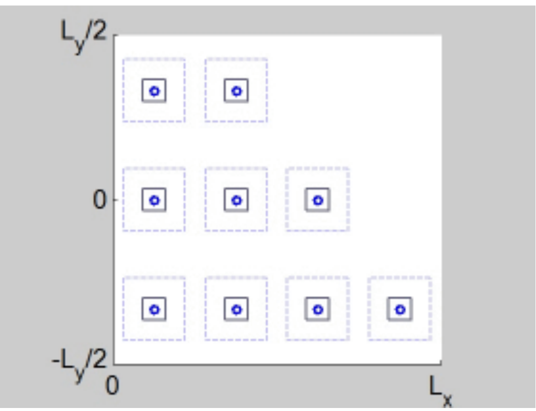
About Me?

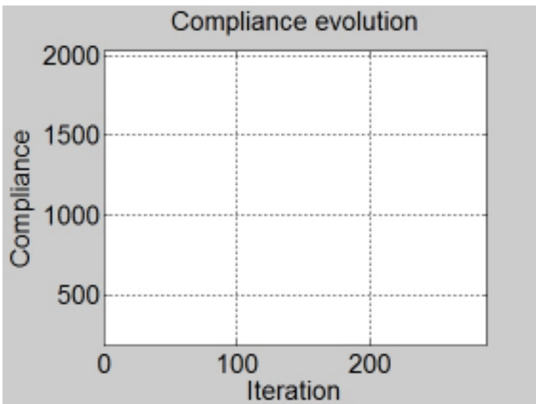
http://www.institut-clement-ader.org/pageperso.php?id=jmorlier

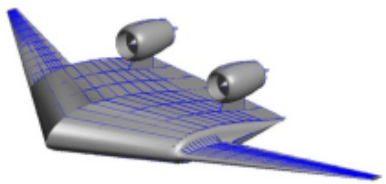
- Professor in Structural and Multidisciplinary Optimization
- Research Lab (ICA)
- 5 PhDs, 1 postdoc



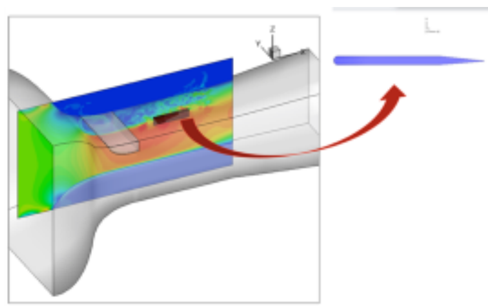








$$
\begin{array}{ll}
\min\limits_{\substack{(\boldsymbol{t},\boldsymbol{A}) \in \mathbb{R}^{2N} \\ \boldsymbol{c} \in \Gamma^N}} & W(\boldsymbol{c},\boldsymbol{t},\boldsymbol{A}) \\
\text{Subjected to:} & \boldsymbol{RF}(\boldsymbol{c},\boldsymbol{t},\boldsymbol{A},IL(\boldsymbol{c},\boldsymbol{t},\boldsymbol{A})) \geq 1 \\
 & G(\boldsymbol{c},\boldsymbol{t},\boldsymbol{A}) \leq 0 \\
 & \underline{t}(\boldsymbol{c}) \leq \boldsymbol{t} \leq \overline{t}(\boldsymbol{c}) \\
 & \underline{\alpha}(\boldsymbol{c}) \leq \dfrac{\boldsymbol{A}}{\boldsymbol{b}\boldsymbol{t}} \leq \overline{\alpha}(\boldsymbol{c})
\end{array}
$$



Outlines

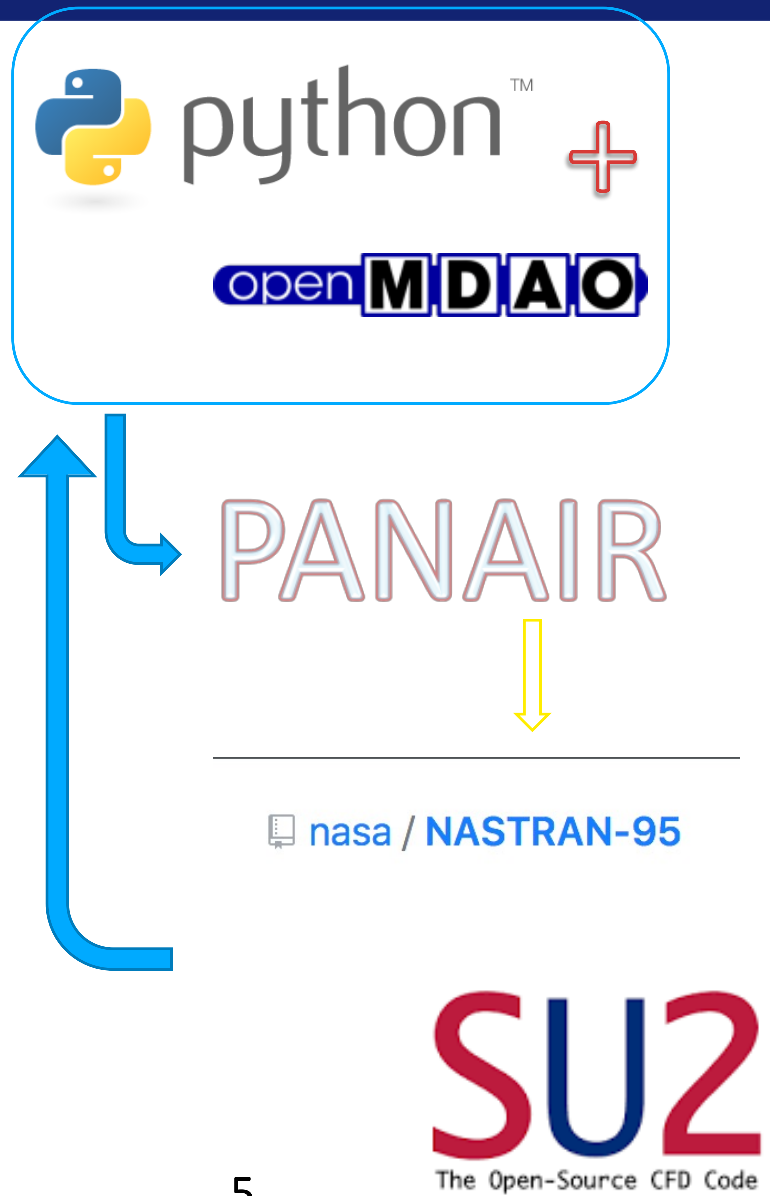
1. The Big Picture
2. OpenMDAO strategy
3. Modes tracking

Main idea

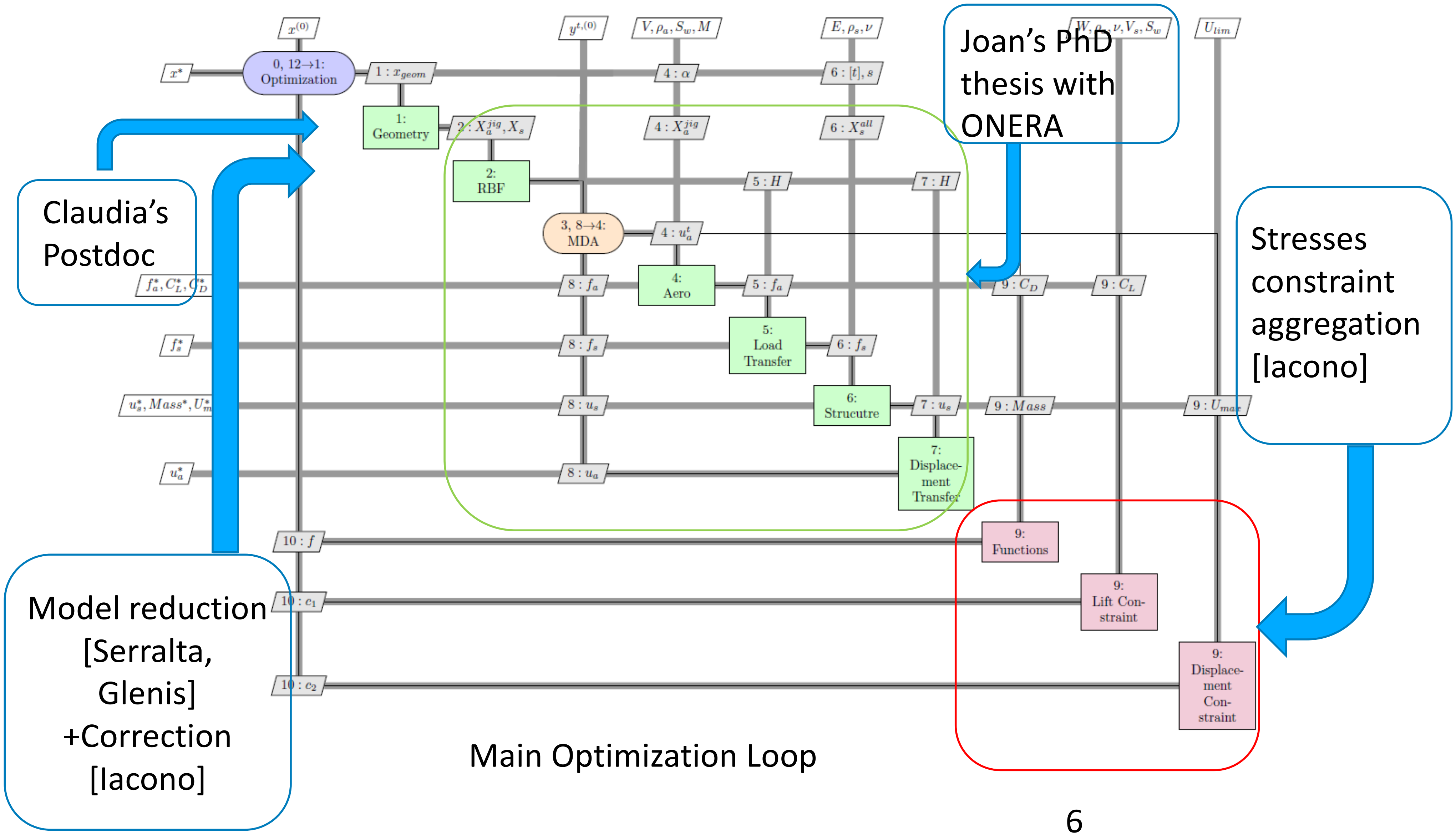
To develop an OpenSource Multidisciplinary Design Analysis & Optimization toolkit including CAD, aerodynamic, sizing (stress, modal+aeroelasticity)

Python library that can be re-used by students (PhDs, Internships etc…) to perform aeroelastic optimizations

- Versatile (Standard AC / BWB)
- reduced computational cost



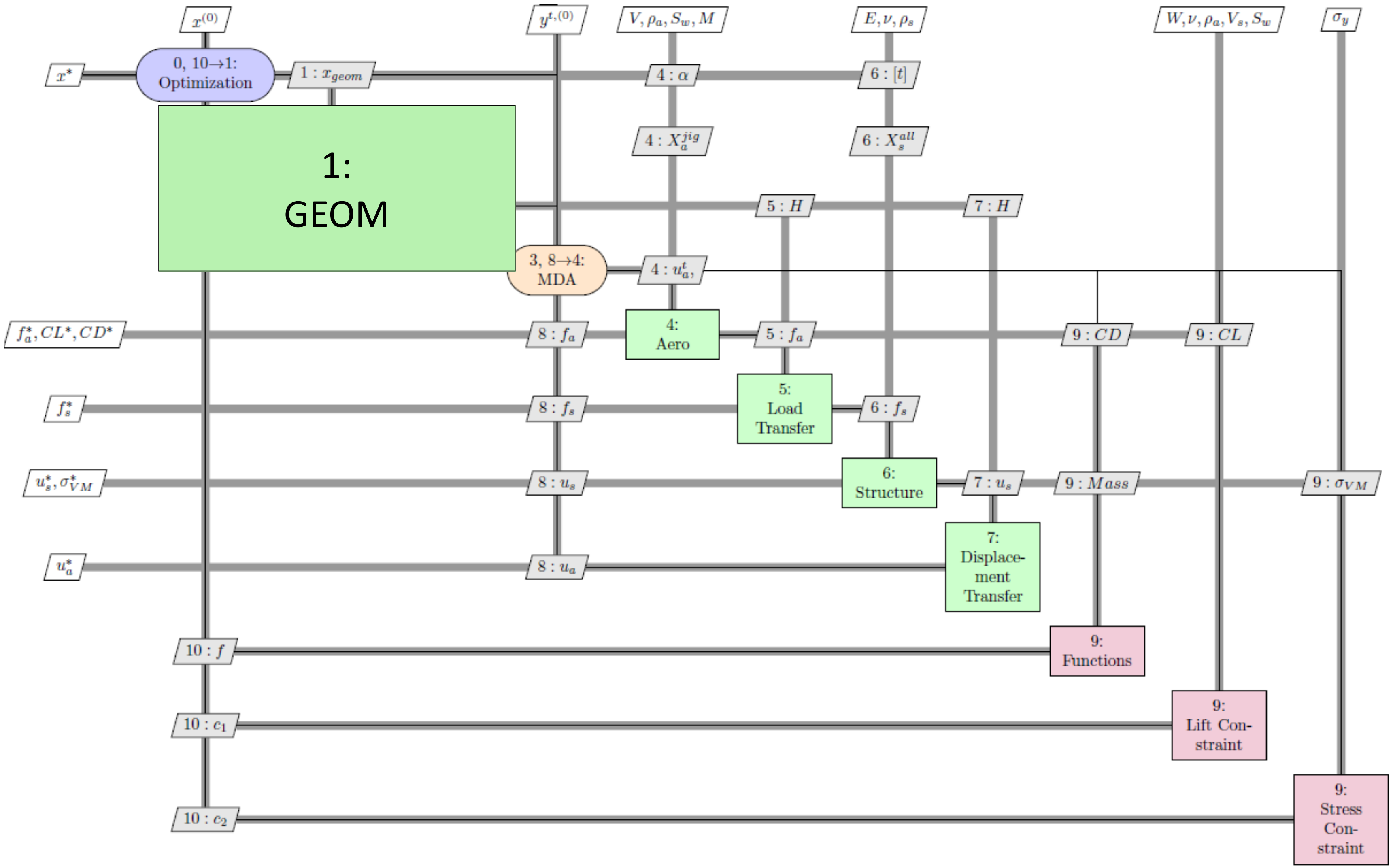
Team work



Main Optimization Loop

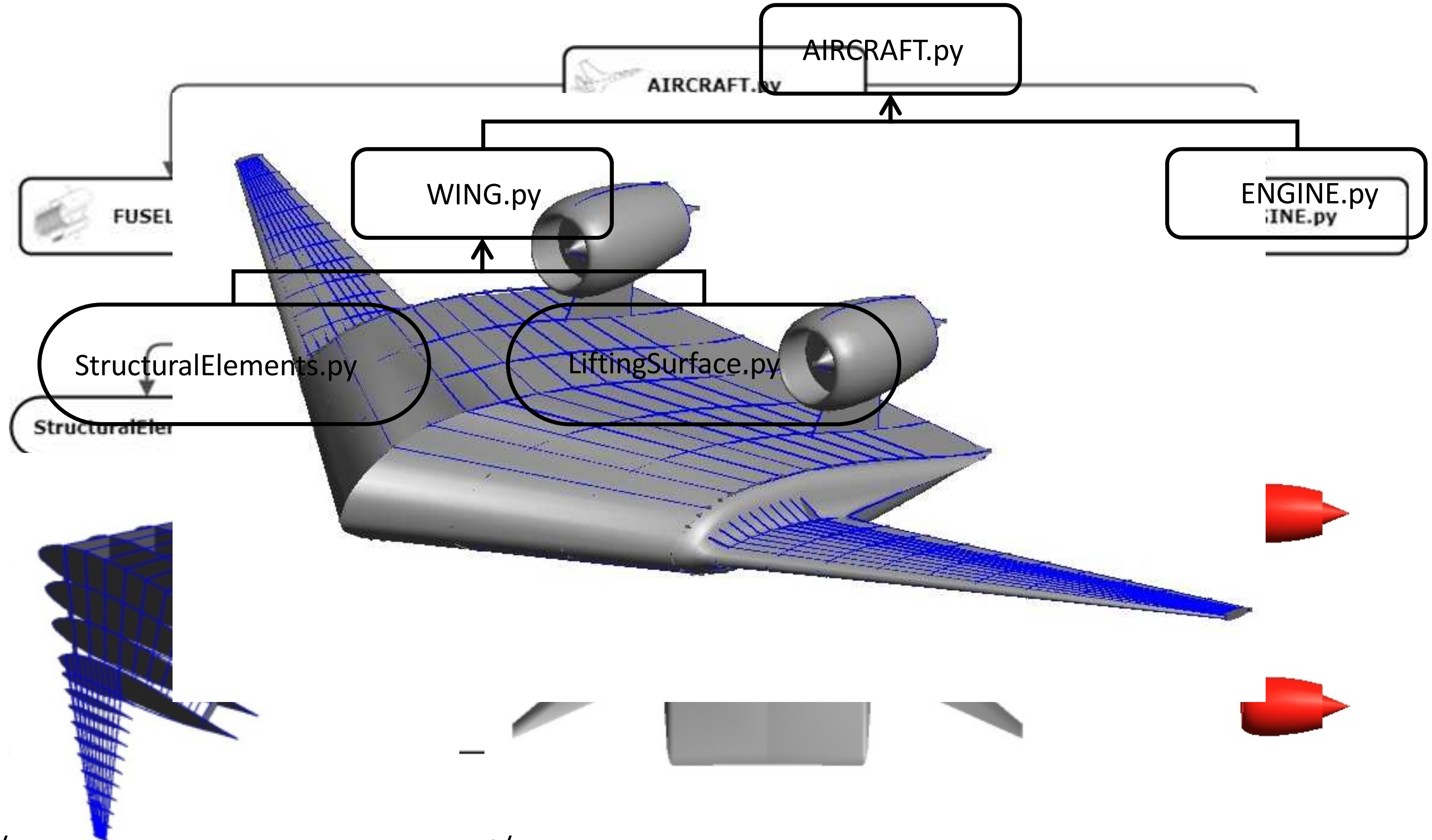
Optimization Problem

Geometrical Modeler



Optimization Problem
Geometrical Modeler

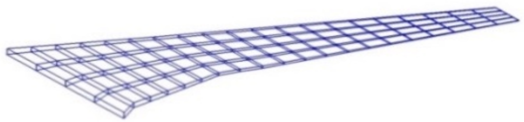
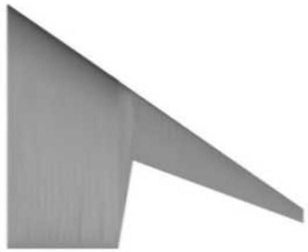
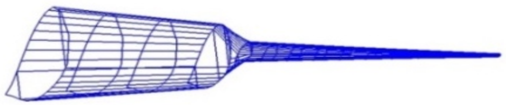
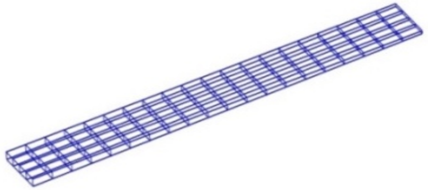
- Rely on the Pythonocc, a Python library, to provide 3D modeling features.
- The bottom-up construction philosophy is inspired by occ_airconics[1], a scripted aircraft geometry package for Python.



[1] http://occ-airconics.readthedocs.io/en/latest/

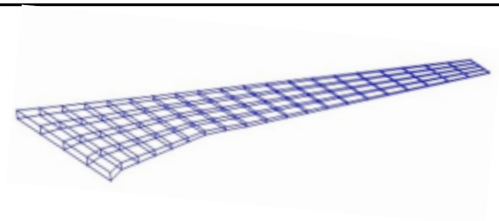
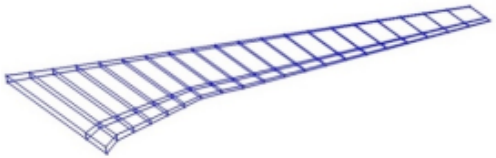
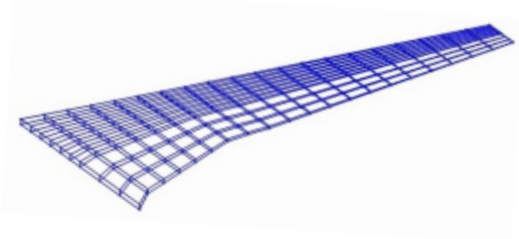
Optimization Problem
Geometrical Modeler

All types of body shape may be reproduced, here some wing examples:

Aerodynamic Surface	Airframe	Wing Type
		CRM
		BWB
		GOLAND

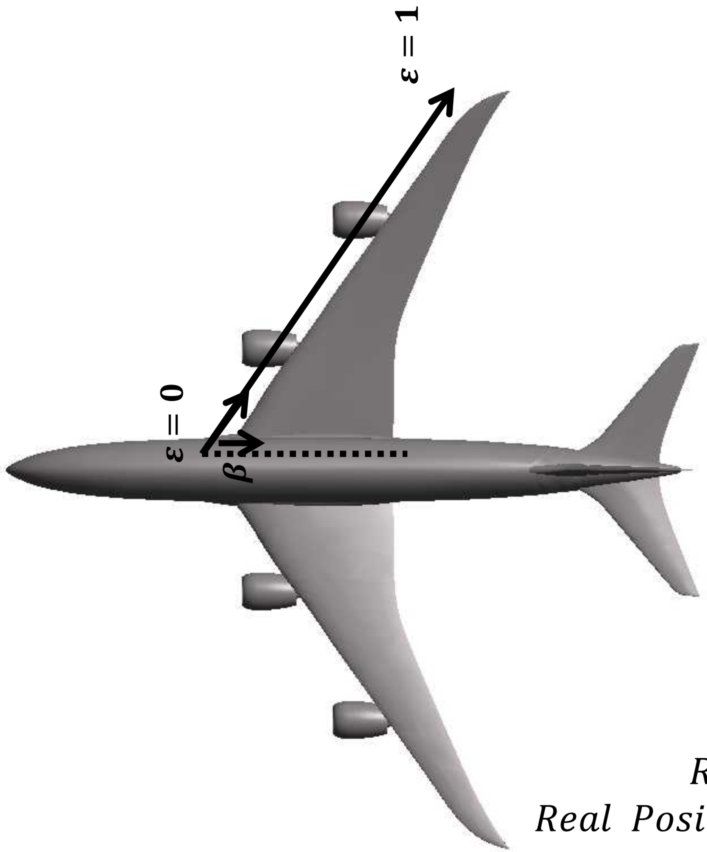
Optimization Problem
Geometrical Modeler

Many types of airframe:

Number of Ribs	
Spars Position	
Number and Position of Stringers	

Optimization Problem
Geometrical Modeler

Parametrization

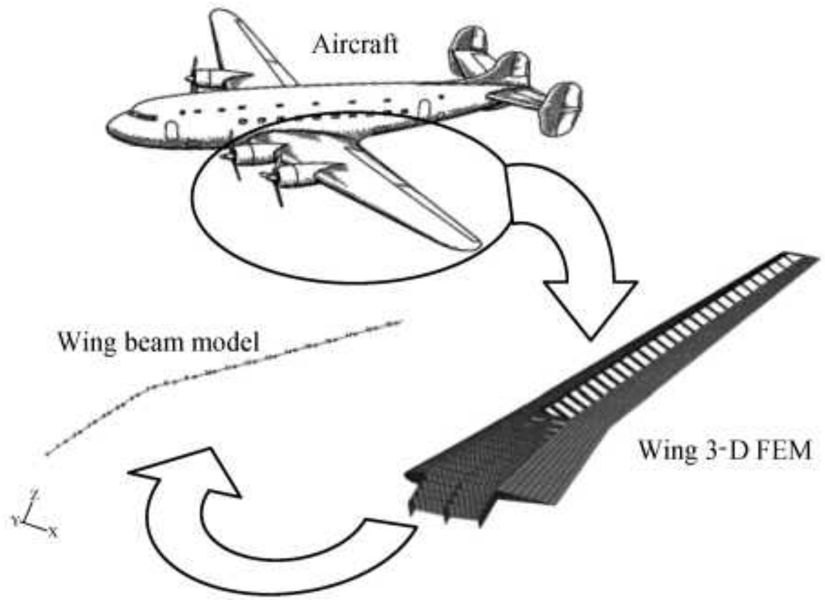


c_n	$\cdots$	$c_1 \ \ c_2$	***Chord***
d_n	$\cdots$	$d_1 \ \ d_2$	***Dihedral***
t_n	$\cdots$	$t_1 \ \ t_2$	***Twist***
s_n	$\cdots$	$s_1 \ \ s_2$	***Sweep***

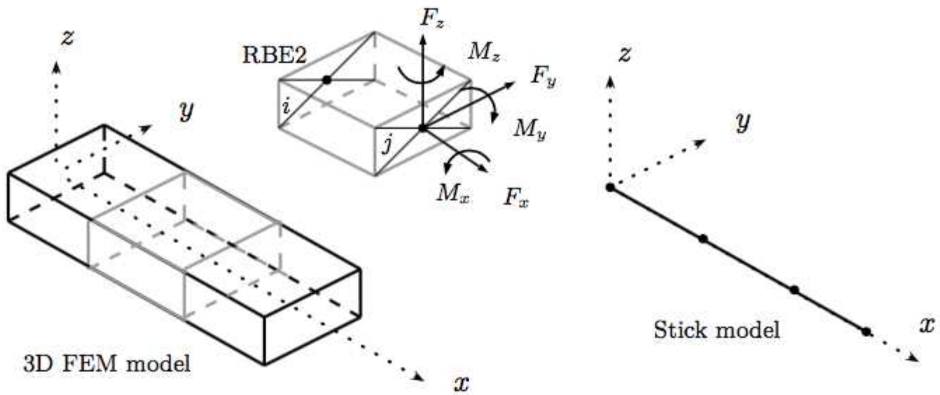
$$Real\ \ Position\ along\ the\ Wing\ Span = \ \varepsilon * \boldsymbol{ScaleFactor}$$
$$Real\ \ Position\ along\ the\ Wing\ Chord = \ \beta * \boldsymbol{ScaleFactor} * \boldsymbol{ChordFactor}$$

wing body model reduction

Reduce the computational cost from
3D model analysis to 1D model analysis.



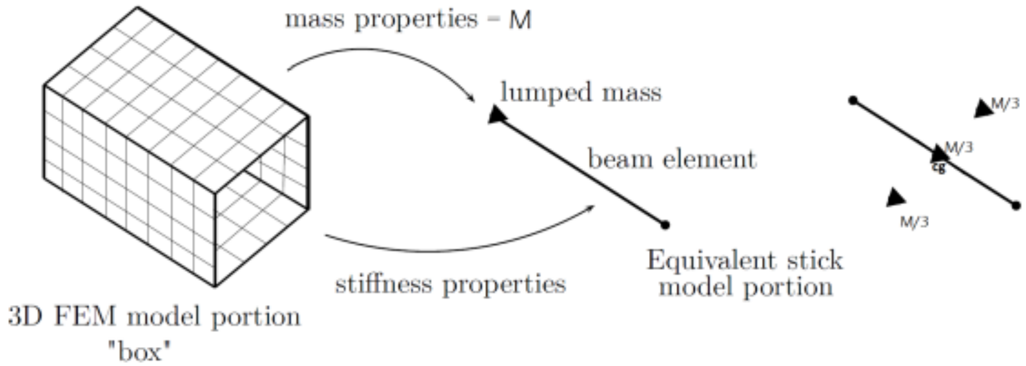
- Equivalent statics and dynamics
- Compatible with main project's targets



Serralta J.,Glenis D., Blended wing body model reduction for aeroelasticit,2017.

Export stiffness and mass properties from the 3D FEM model to the equivalent 1D Beam model using Nastran Weight Generator instrument and stiffness matrix comparison.

MAC correction



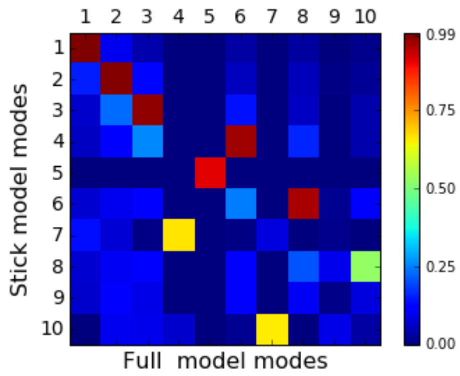
- Correction of mass distribution

  Split the mass of the box in 3 equal parts positioned in the cg, in the TE and in the LE.

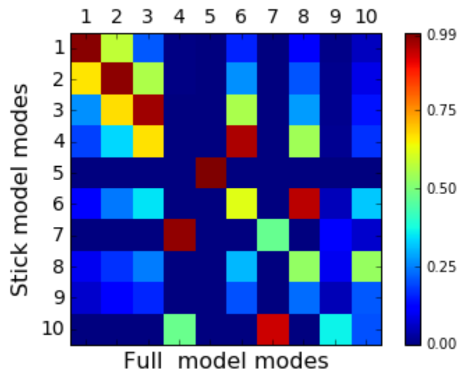
- Automatic modes pairing

  Based on the Modal Assurance Criteria (MAC). Double match with the translation DOFs and with the rotation DOFs

$$MAC(\Phi_1, \Phi_2) = \frac{(\Phi_1^T \cdot \Phi_2)^2}{||\Phi_1||^2 \cdot ||\Phi_2||^2}$$

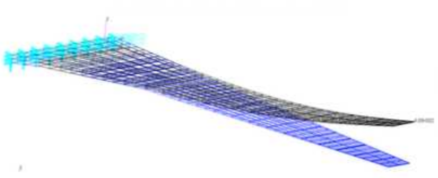


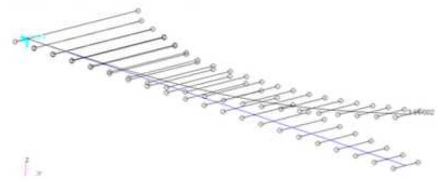
Translation DOFs

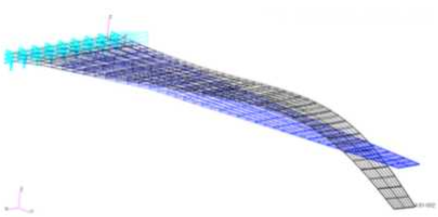


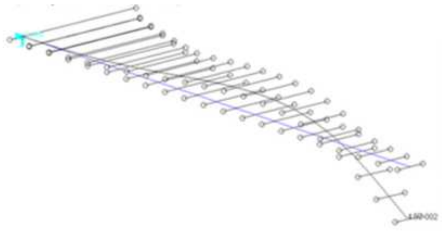
Rotation DOFs

CRM WING

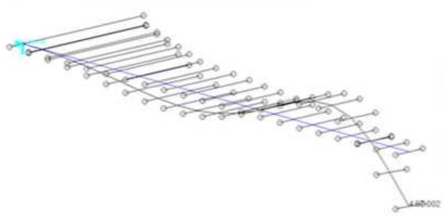

(a) Full model - Mode 1

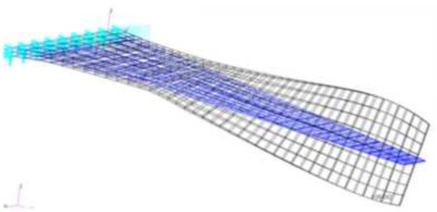

(b) Stick model - Mode 1

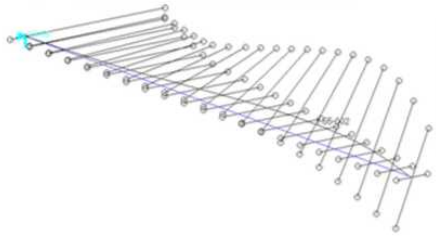

(c) Full model - Mode 2

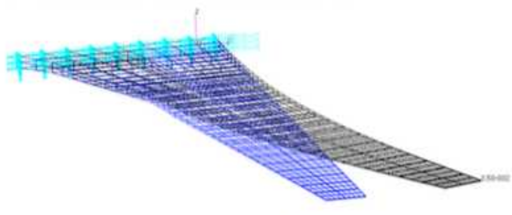

(d) Stick model - Mode 2

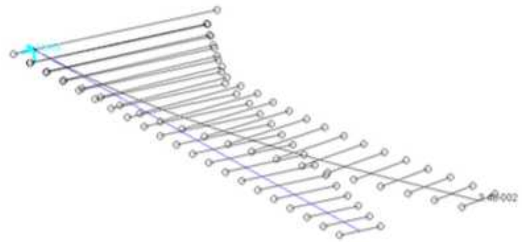

(e) Full model - Mode 3

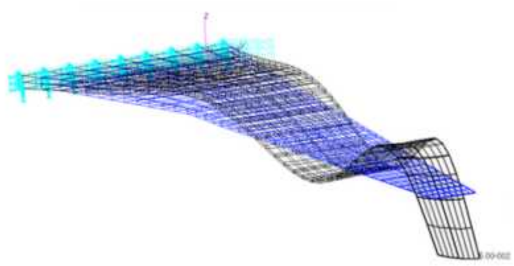

(f) Stick model - Mode 3

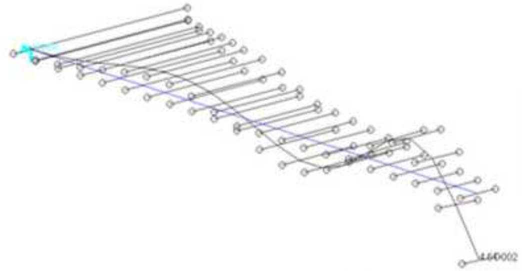

(g) Full model - Mode 4

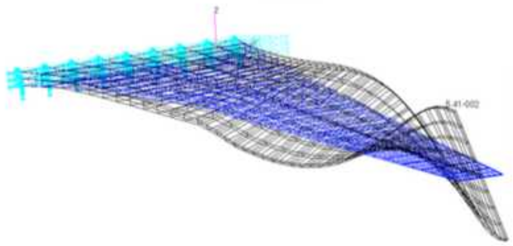

(h) Stick model - Mode 7

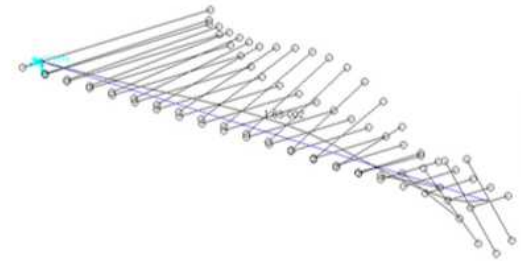

(a) Full model - Mode 5


(b) Stick model - Mode 5


(c) Full model - Mode 6


(d) Stick model - Mode 4

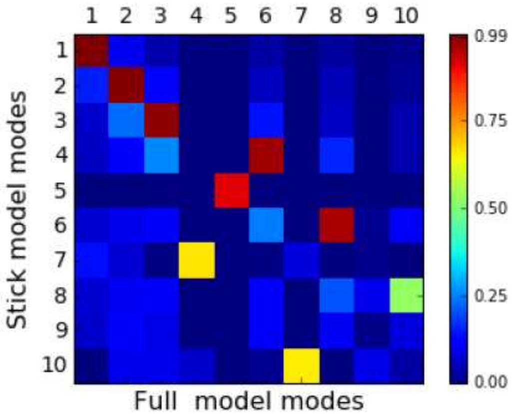

(e) Full model - Mode 7

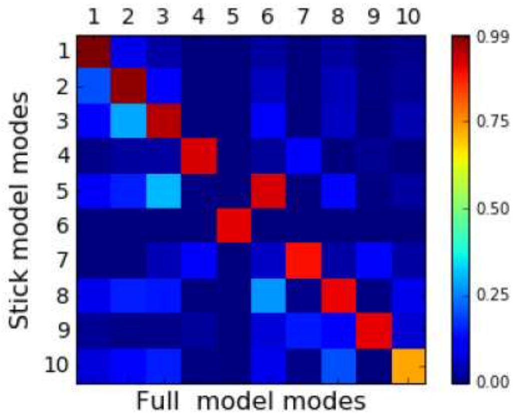

(f) Stick model - Mode 10

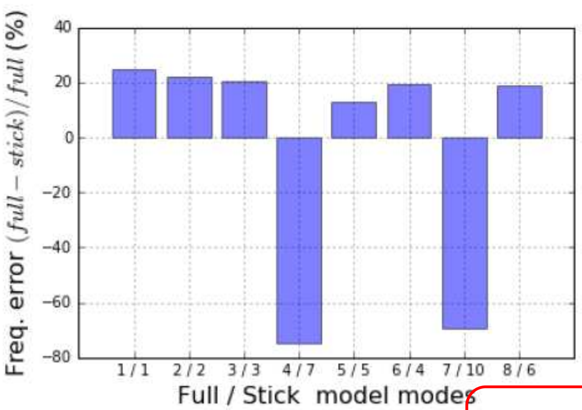
Preliminary Results

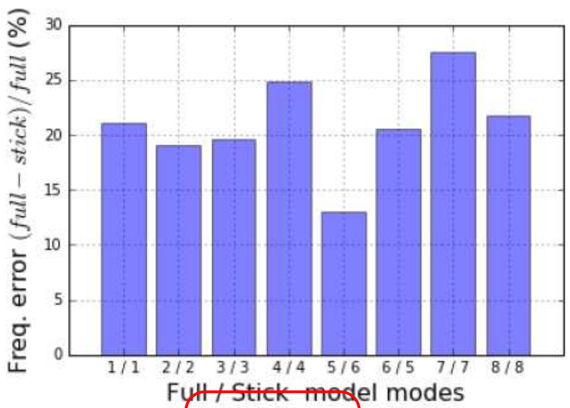
1 Lumped mass in the CG

3 Lumped mass (LE,CG,TE)







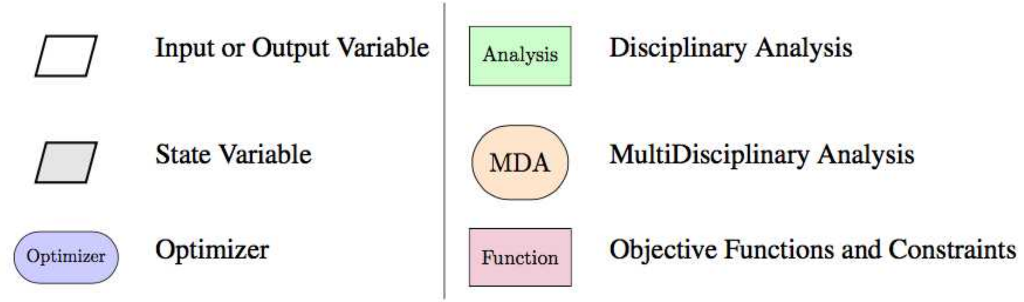


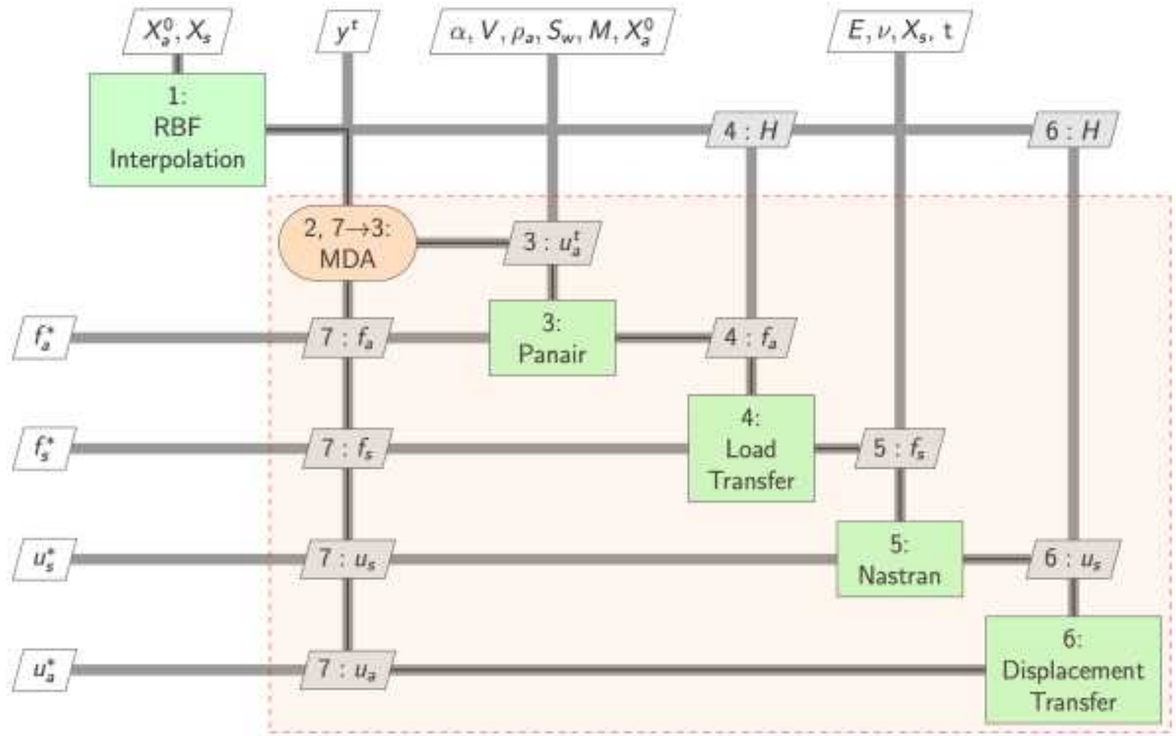
[**MODE 1**:24.53%, **MODE 2**:21.88%, **MODE 3**:20.66%, **MODE 4**:-74.55%, **MODE 5**:13.13%, **MODE 6**: 19.57%, **MODE 7**: -69.21%, **MODE 8**: 18.59%]

[**MODE 1**:21.06%, **MODE 2**:19.00%, **MODE 3**:19.65%, **MODE 4**:24.79%, **MODE 5**:12.98%, **MODE 6**: 20.61%, **MODE 7**: 27.52%, **MODE 8**: 21.78%]

- Significant improvements on torsional modes
- More similar modal shapes
- Small improvements on other modes

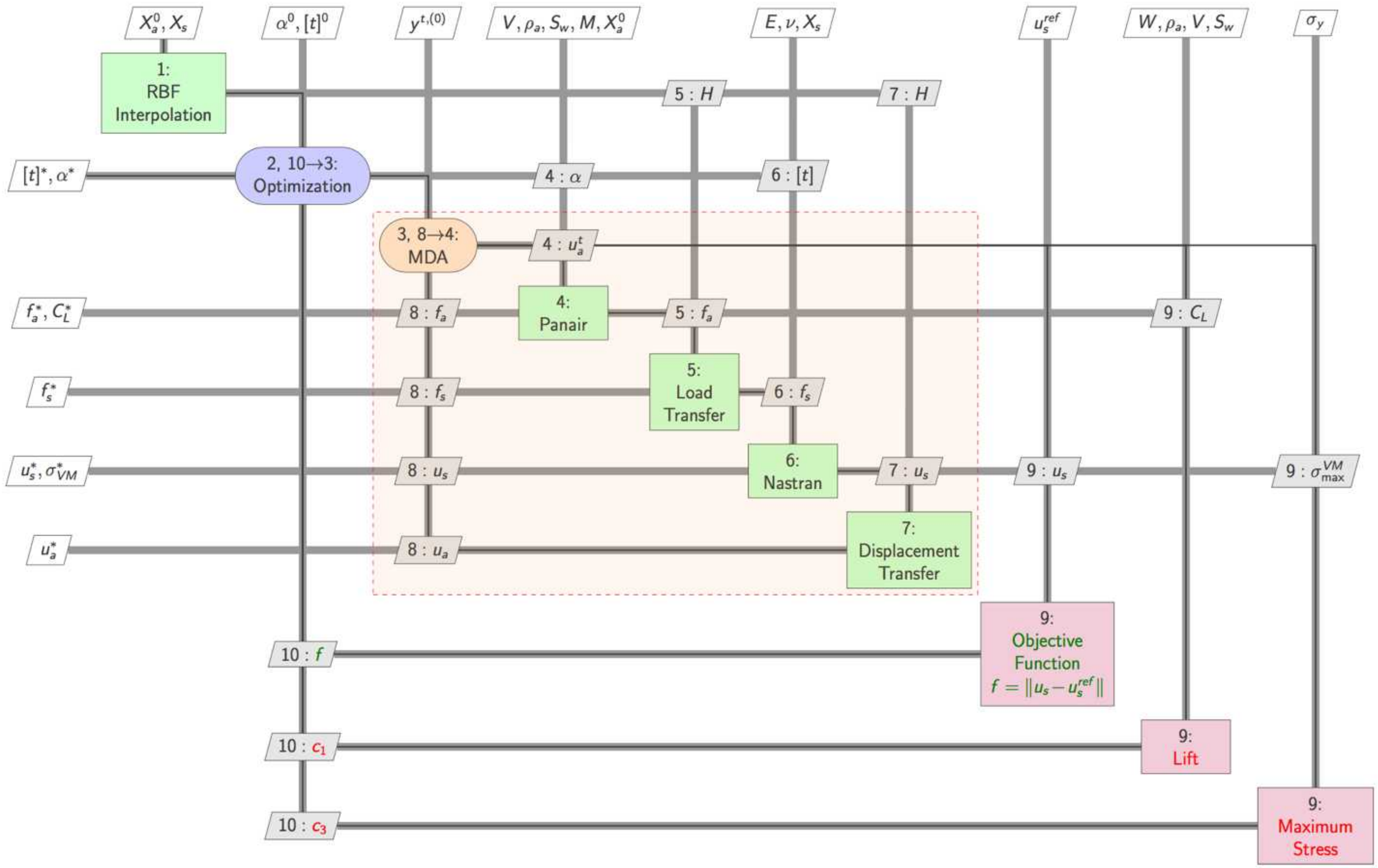
Preliminary works MDA: Static Aeroelasticity XDSM



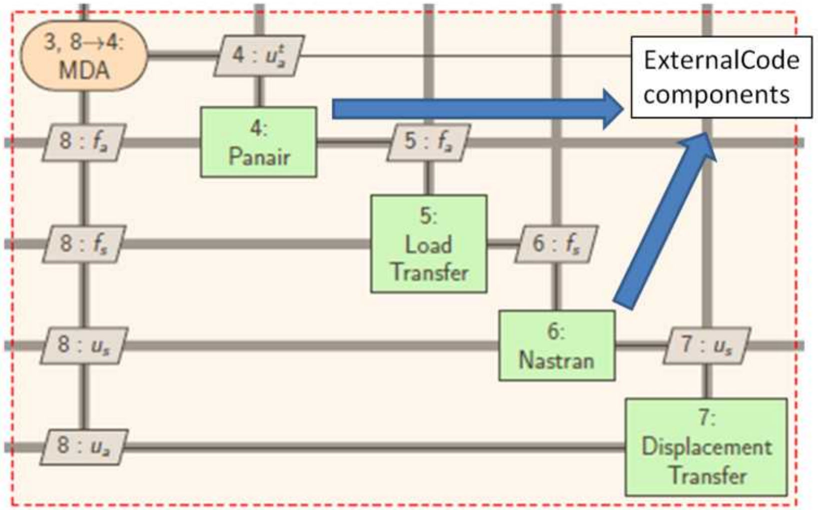


[Lambe and Martins, Structural and Multidisciplinary Optimization, 2012]

Static aeroelasticity Optimization

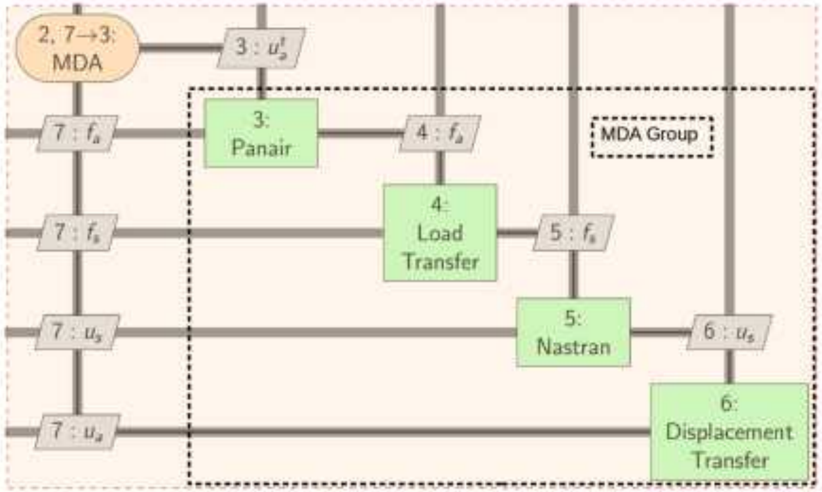


Implementation in OpenMDAO (1)



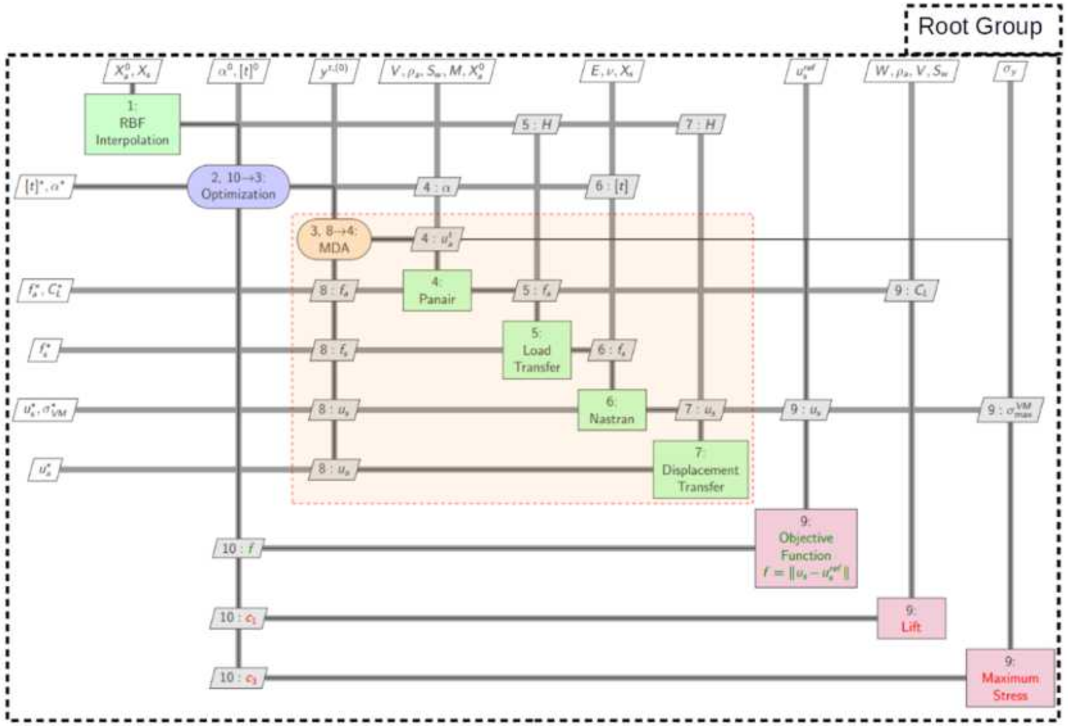
- ExternalCode type of component
- From the inputs of the component, the input file of the external analysis code is written
- Analysis is run
- Output files are read and the outputs are set accordingly

Implementation in OpenMDAO (2)



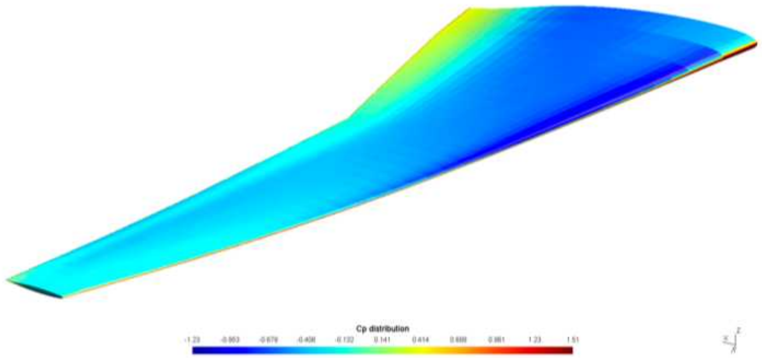
- All components are added into a group
- The nonlinear solver of the group is defined as Gauss–Seidel

Implementation in OpenMDAO (3)

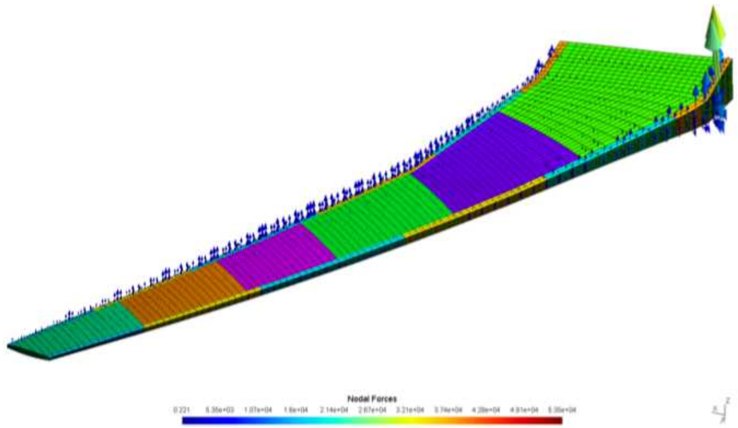


- The rest of components and MDA group are added larger group
  - The optimizer is defined as the problem's driver
  - MDF architecture

Coupling OpenNastran+ Adflow (SU2)



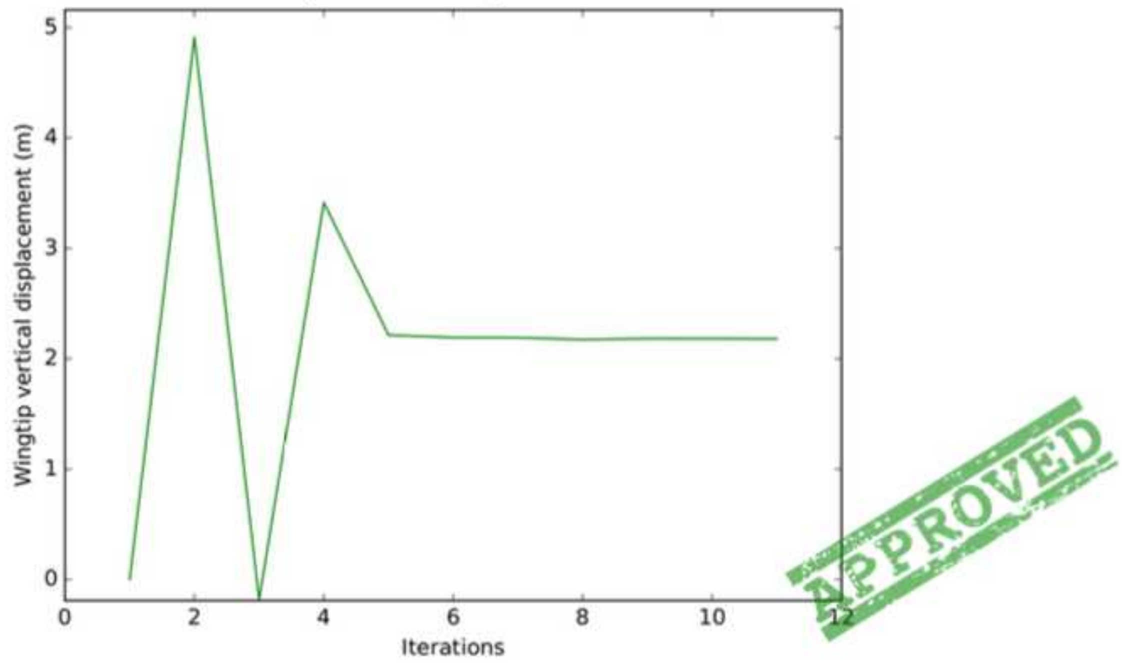
→ Distribution de pression



Forces sur ← la structure

Results

Couplage ADflow (CFD Hi-Fi) & Nastran95:

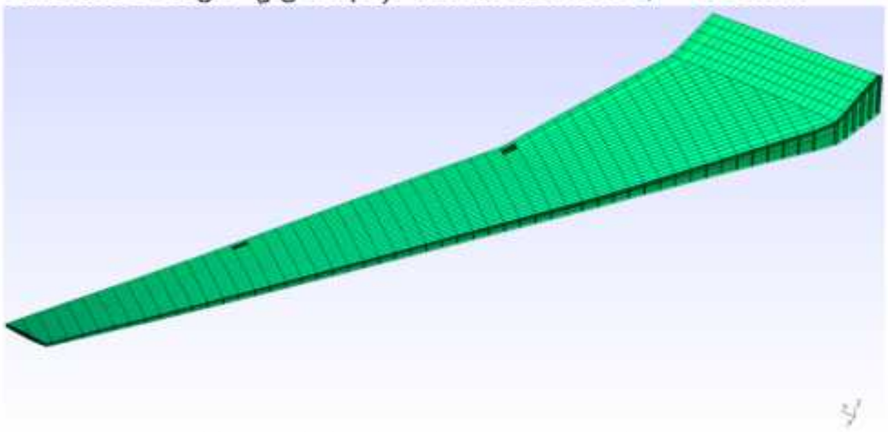


Blind identification

- From ONERA Chatillon's optimized CRM (thanks to C. Blondeau)

FROM A GIVEN MODAL BASIS AND GEOMETRY, CAN WE UPDATE A FEM ?

Reference Design* (jig shape): For all elements $t_r = 8.89mm$



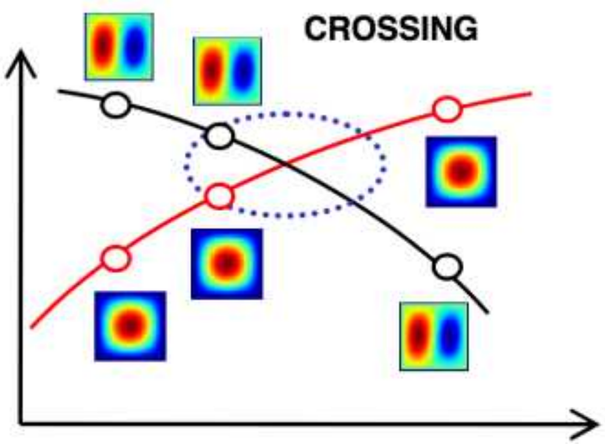
Model provided by T. Achard and C. Blondeau*

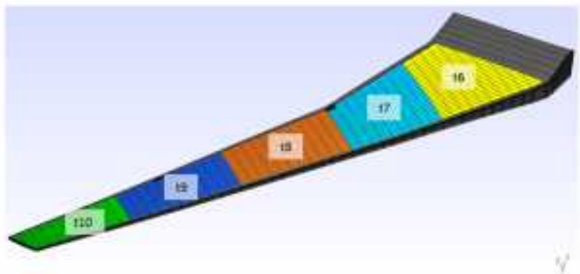
Modes pairing/tracking: Problem definition

Objective Function		Dimension	Bounds
Mode shape difference minimization	$\min(N - \mathrm{trace}(\mathrm{MAC}([\Phi_r], [\Phi_m])))$	$\mathbb{R}$	
Design Variables			
Skin thicknesses vector	$[t]$	$\mathbb{R}^{10}$	$[0.0889, 26.67]$ mm
Constraints			
Reduced frequency matching	$\|\omega_r - \omega_m\| = 0$	$\mathbb{R}$	
Mass matching	$M_r - M_m = 0$	$\mathbb{R}$	
Generalized masses matching	$\|m_r - m_m\| = 0$	$\mathbb{R}$	

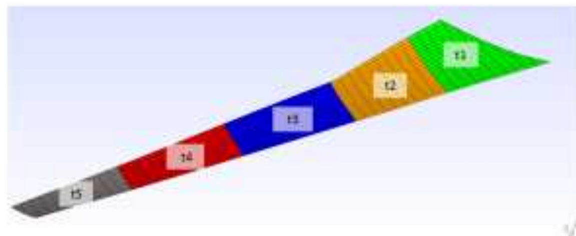
Thickness initialization :Vector of size 10 t1-t10 (meter):

array([0.01863388, 0.01661411, 0.01273371, 0.01495363, 0.00847329, 0.01743593, 0.02332176, 0.02023447, 0.02068164, 0.0213995])



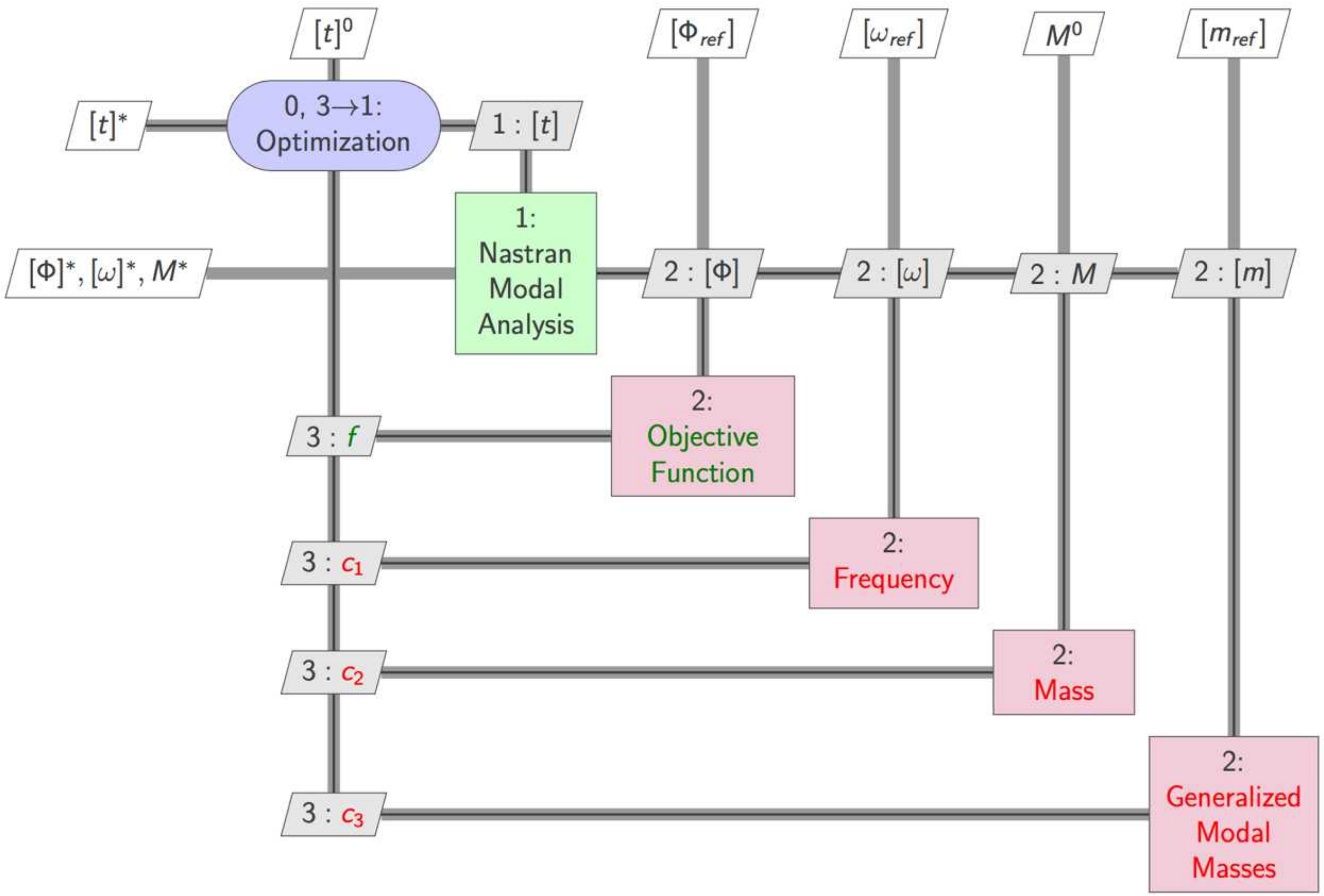


→ Upper skin panels

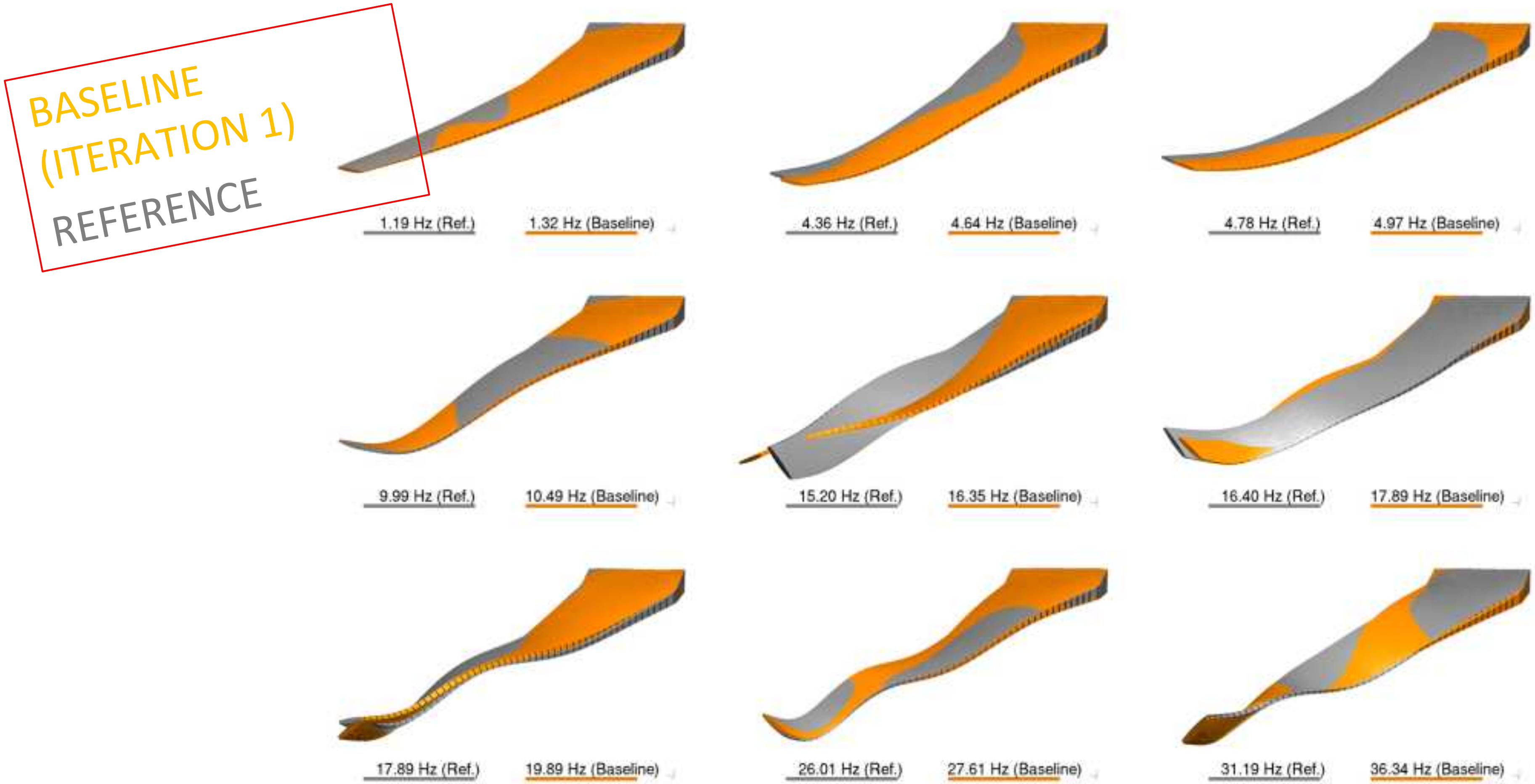


Lower skin panels ←

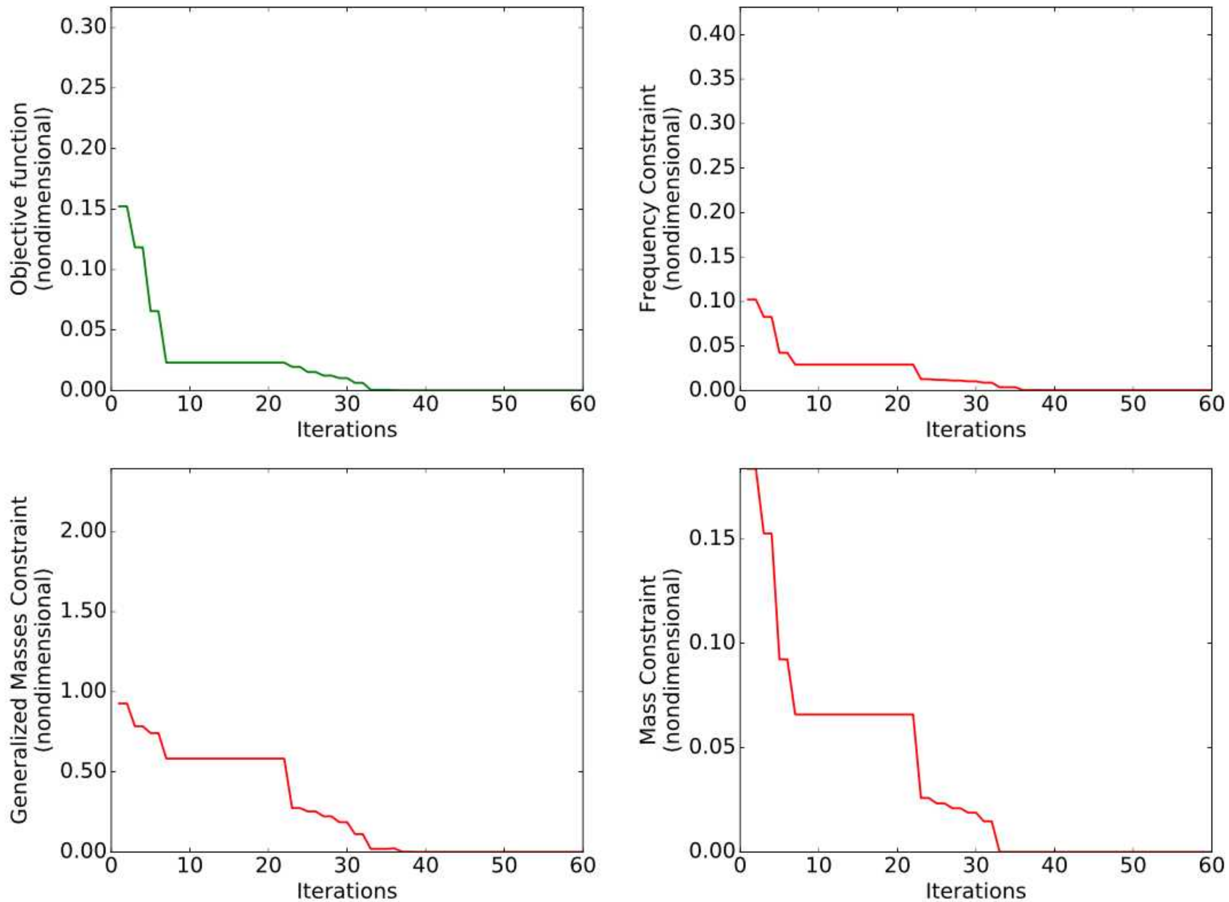
Modal Optimization



1st Validation CRM Blind Updating

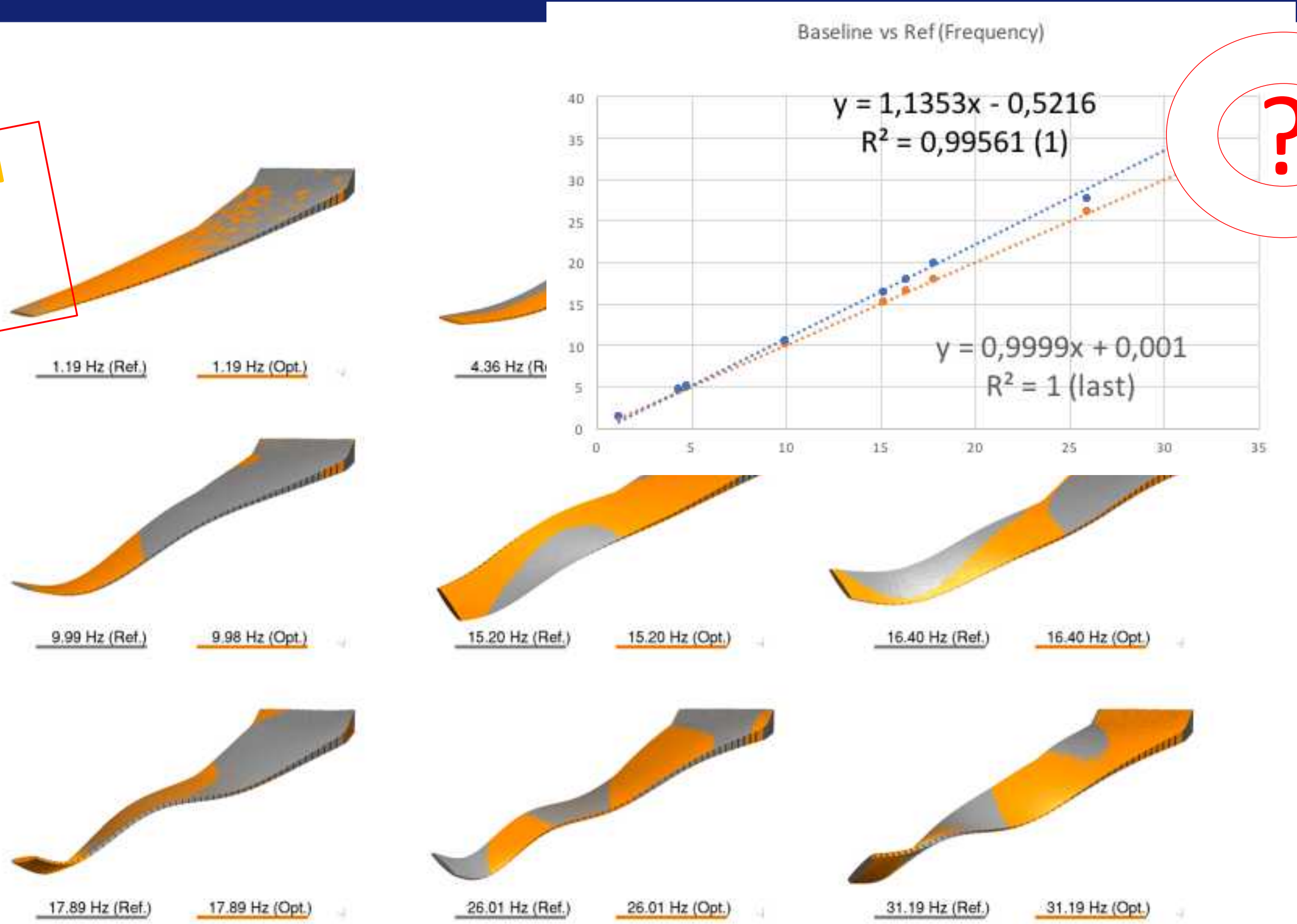


Results of the Optimization (SLSQP)



Graphicaly AT CONVERGENCE...

BASELINE (ITERATION Last)
REFERENCE

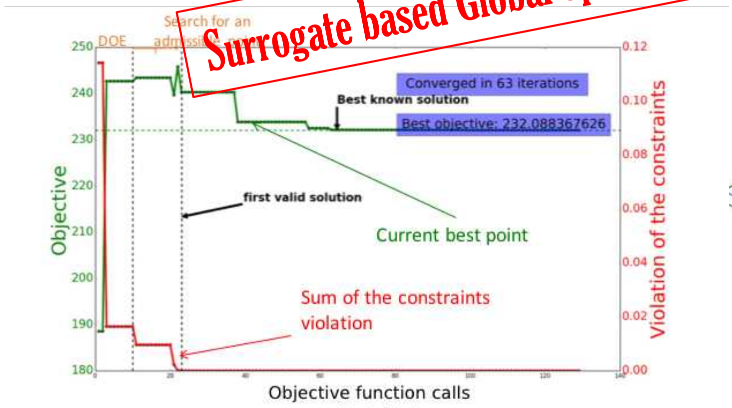


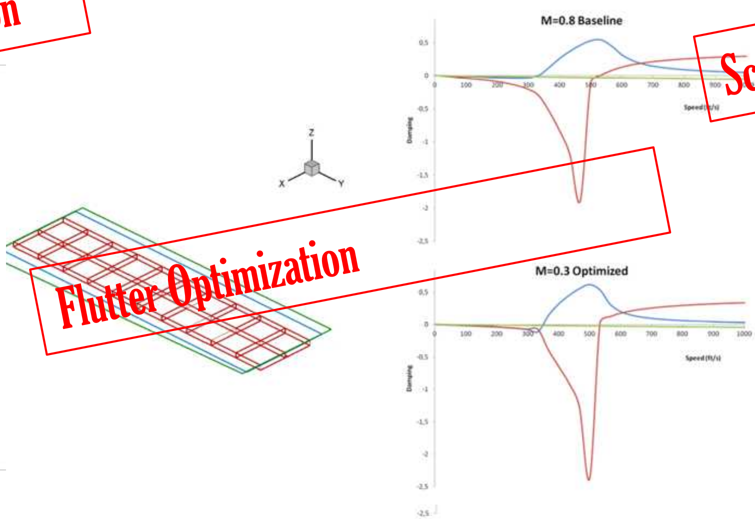
Papers&conf

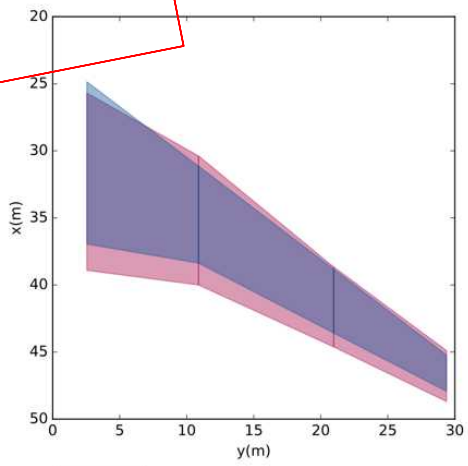
J. Mas Colomer et al Similarity Maximization of a Scaled Aeroelastic Flight Demonstrator via Multidisciplinary Optimization. AIAA SCITECH 2017

J. Mas Colomer, et al, Static and Dynamic Aeroelastic Scaling of the CRM Wing via Multidisciplinary Optimization. WCSMO12 2017

Several Papers in preparation





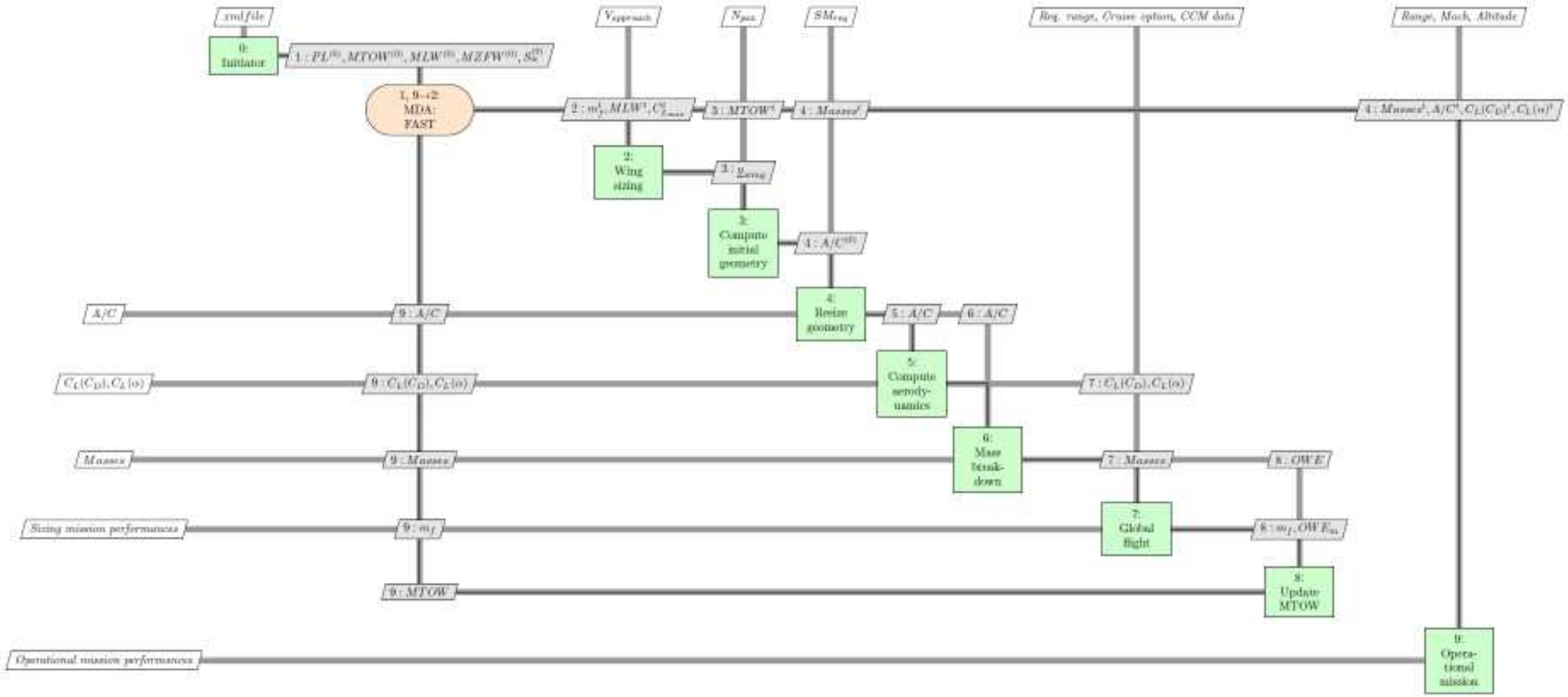


Optimized planform (red) and baseline (blue).

FAST COMPATIBILITY

Interoperating framewok: can be called in FAST as High Fidelity tool (Link with A. Sgueglia's thesis)

ONERA
THE FRENCH AEROSPACE LAB



New students

- MAE Student

Ashka Guptay (similarity in flutter)

- SUPAERO's student

Michele PIOLI (PZT modeling)

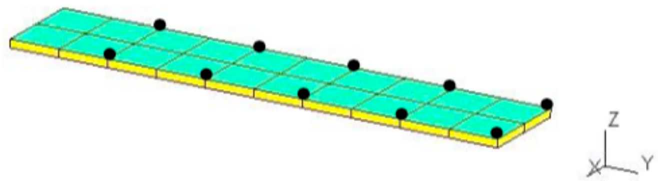


Figure 2: *GOLAND Wing Geometry*

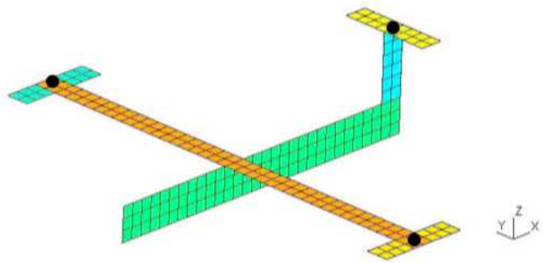
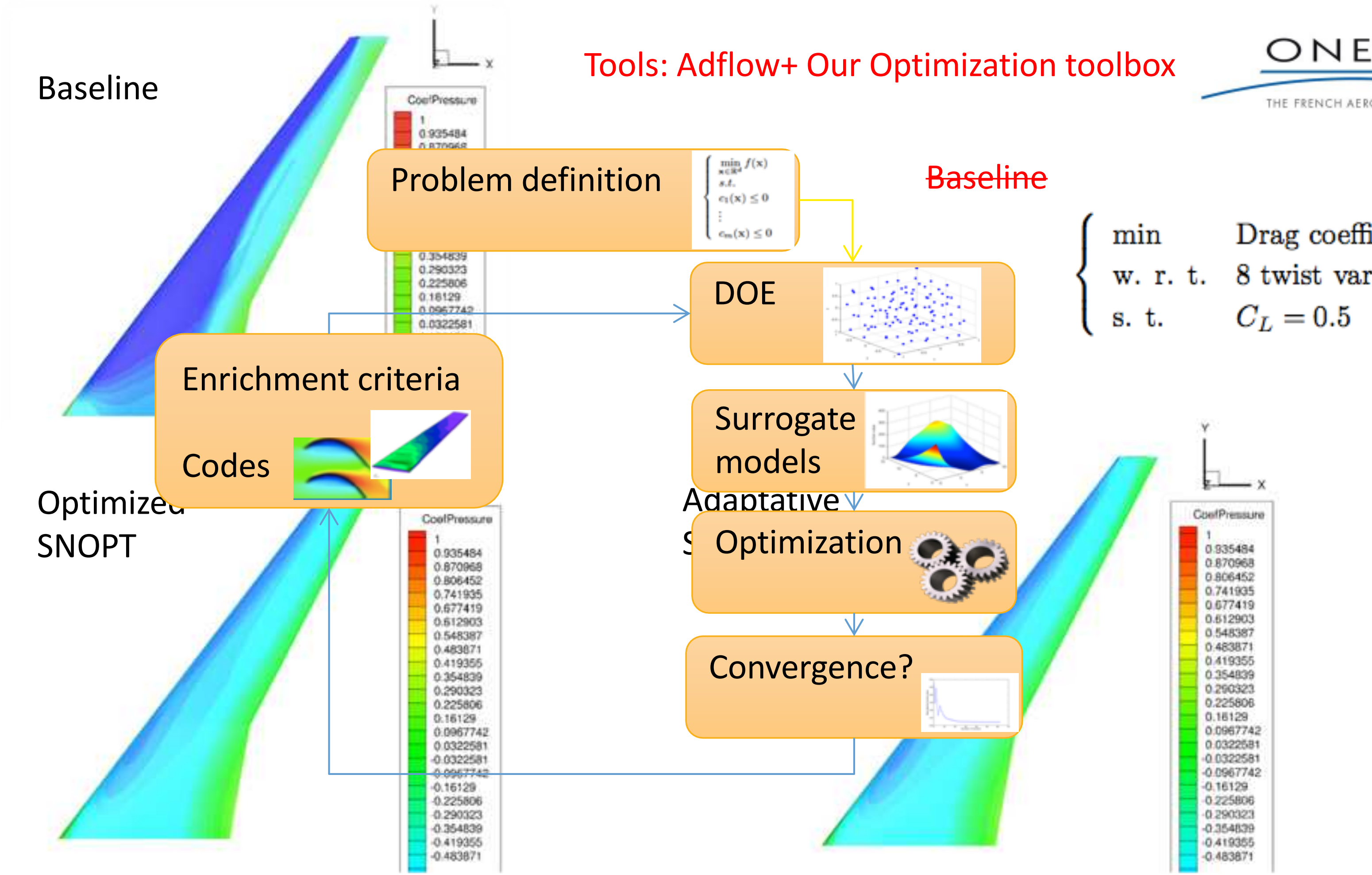


Figure 3: *GARTEUR SM-AG19 Geometry*

Another example of international collaboration

Tools: Adflow+ Our Optimization toolbox



$$\begin{cases} \text{min} & \text{Drag coefficient, } C_D \times 10^4 \\ \text{w. r. t.} & \text{8 twist variables} \in [-10, 10] \\ \text{s. t.} & C_L = 0.5 \end{cases}$$

N. Bartoli, T. Lefevbre, N. Bons, M. Bouhlel, S. Dubreuil, R. Olivanti, J.R.R. Martins and J. Morlier. An adaptive optimization strategy based on mixture of experts for wing aerodynamic design optimization. Proceedings of AIAA AVIATION Forum 5-9 June 2017, Denver, Colorado 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference 2017

Lead also to an OpenSource toolbox

Visit : https://github.com/SMTorg/SMT

Surrogate models

AEROSPACE ENGINEERING
UNIVERSITY of MICHIGAN

NASA isae SUPAERO ONERA

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SMT: Surrogate Modeling Toolbox

The surrogate model toolbox (SMT) is an open-source Python package consisting of libraries of surrogate modeling methods (e.g., radial basis functions, kriging), sampling methods, and benchmarking problems. SMT is designed to make it easy for developers to implement new surrogate models in a well-tested and well-document platform, and for users to have a library of surrogate modeling methods with which to use and compare methods.

The code is available open-source on GitHub.

Focus on derivatives

SMT is meant to be a general library for surrogate modeling (also known as metamodeling, interpolation, and regression), but its distinguishing characteristic is its focus on derivatives, e.g., to be used for gradient-based optimization. A surrogate model can be represented mathematically as

$$y = f(\mathbf{x}, \mathbf{xt}, \mathbf{yt}),$$

where $\mathbf{xt} \in \mathbb{R}^{nt \times nx}$ contains the training inputs, $\mathbf{yt} \in \mathbb{R}^{nt}$ contains the training outputs, $\mathbf{x} \in \mathbb{R}^{nx}$ contains the prediction inputs, and $y \in \mathbb{R}$ contains the prediction outputs. There are three types of derivatives of interest in SMT:

1. Derivatives (dy/dx): derivatives of predicted outputs with respect to the inputs at which the model is evaluated.
2. Training derivatives (dyt/dxt): derivatives of training outputs, given as part of the training data set, e.g., for gradient-enhanced kriging.
3. Output derivatives (dy/dyt): derivatives of predicted outputs with respect to training outputs, representing how the prediction changes if the training outputs change and the surrogate model is re-trained.

Not all surrogate modeling methods support or are required to support all three types of derivatives; all are optional.

Conclusions

- Team work on 3 years
- Reusability- Reproducibility
- Use of standard academic test cases: Goland, Garteur, Join Wing sensorcraft, CRM for validation
- Good performance of the Surrogate-based optimization methods versus Gradient-based
- Strong interaction between fidelities (Fast compatibility for Conceptual Design, DLM/Panair/Adflow in aerodynamic, model reduction in structural analysis +aeroelasticity)
- Many application in Demonstrator aeroelastic similarity (for testing new concepts on small AC)
- High level of interaction with ONERA/UoM

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