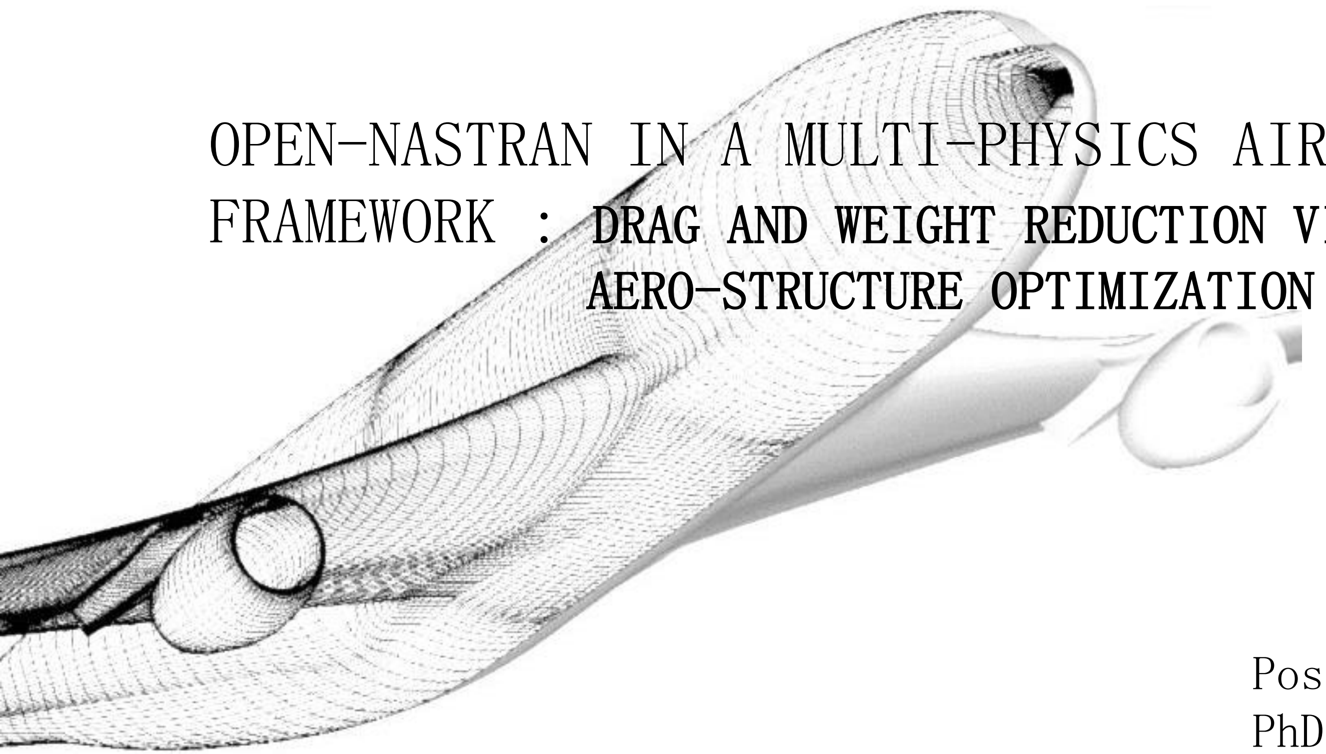
First European Workshop

12-13 October 2017, Toulouse

OPEN-NASTRAN IN A MULTI-PHYSICS AIRCRAFT DESIGN FRAMEWORK : **DRAG AND WEIGHT REDUCTION VIA COUPLED AERO-STRUCTURE OPTIMIZATION**



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What’s multidisciplinary design optimization and Why it is so important for modern aircraft concepts?

What’s multidisciplinary design optimization?

1 ” *MULTIDISCIPLINARY design optimization (MDO) is a field of engineering that focuses on the use of numerical optimization for the design of systems that involve a number of disciplines or subsystems.*
The performance of a multidisciplinary system is driven not only by the performance of the individual disciplines but also by their interactions.” [R. R. A. Martins and Andrew B. Lambe,” Multidisciplinary Design Optimization: A Survey of Architectures”, AIAA Journal 2013 51:9, 2049-2075]

Why it is so important for modern aircraft concepts?

2 Introduced in early design, it helps to <u>reduce time and cost</u> of the whole design cycle.
The increased complexity of the aircraft design, both in terms of <u>new design solutions</u> than of <u>new technologies and materials</u>.

Content

i. Objectives

ii. Model Fidelity

iii. Optimization Problem

   i. Set-Up
   ii. XDMS Format
   iii. Geometrical Modeler
   iv. Interpolation
   v. MDA Group
      i. Aerodynamic
      ii. Structure
   vi. Constraints

iv. Results on 3D and Reduced 1D

Objectives

Build a Python written Open Sources Multi-Fidelity Aircraft Preliminary Design Framework, based on Aero-Structure Optimization.

Why Python scripted and open source??

- Collaborative Environment.
- Access to a global user community, who proficiently interact with support and solutions.

Which Optimization Solutions?

- Aeroelastic Optimization
  - 3D Model
  - Reduced Model
- Performances Optimization

Model Fidelity

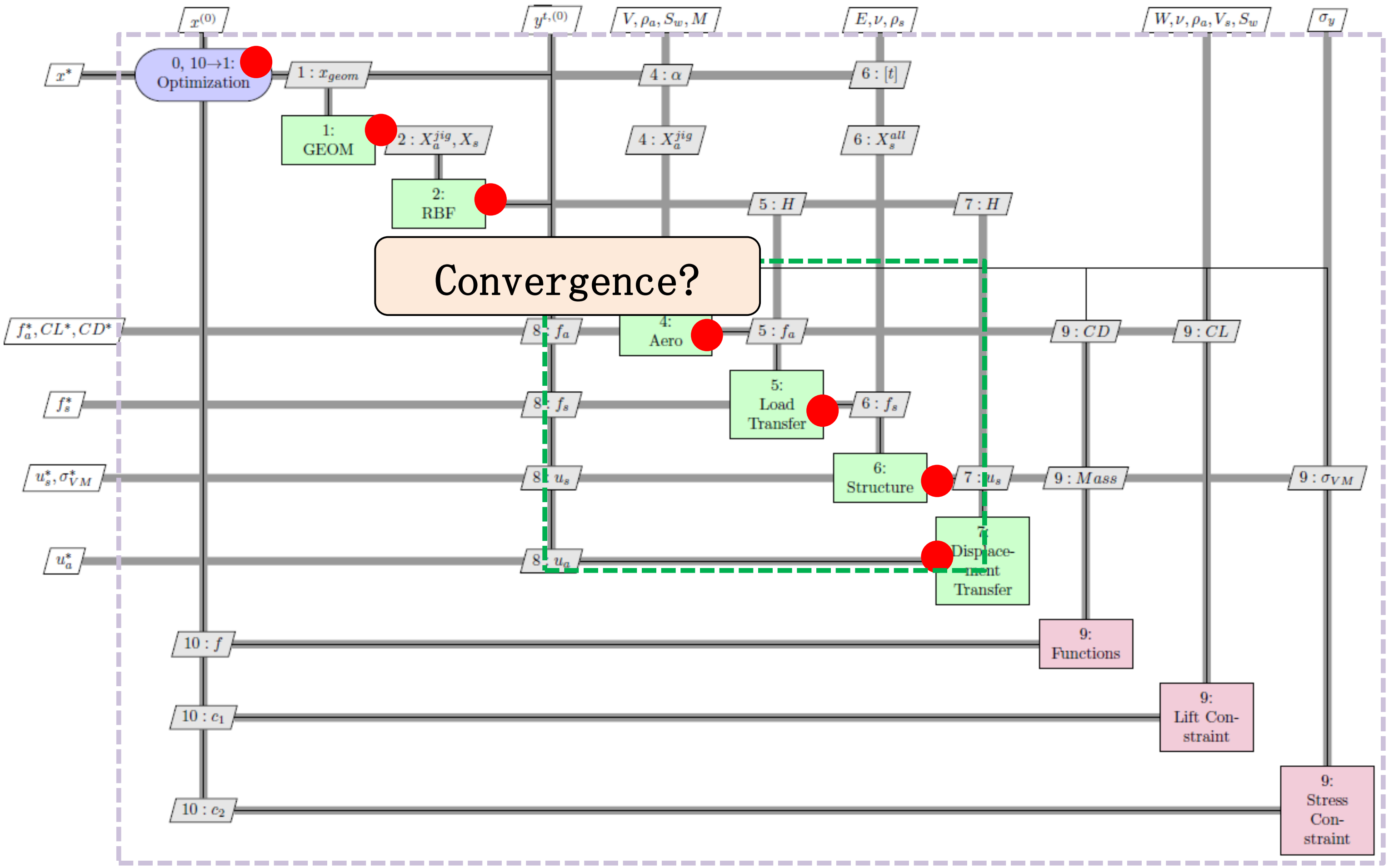
Fidelity Level / Model Type	Low Fidelity	Medium Fidelity	High Fidelity
Geometrical Model	Reduced 1D		Full 3D
Numerical Model/Solution		Panel Method (Panair®) Finite Element (Nastran95®)	

Optimization Problem Set-Up

	Function/Variable	Description	Quantity
Minimize	$a * C_{Di} + b * M$ M C_{Di}	Induced Drag Coeff. + Mass Structure Mass Structure Induced Drag Coeff.	
with respect to	θ $scale\_factor$ $chord\_factor$ $sweep$ mid_spar_pos α t s	Twist Angle Scale Factor Chord Factor Sweep Angle Mid Spar Position Angle of attack Thickness Spar Section Stringers **TOTAL DESIGN VARIABLES**	20 1 1 1 1 1 17 1 **43**
subject to	$C_L = 0.5$ $\sigma_{VM} \leq \sigma_y$	Lift Coefficient Von Mises Stress **TOTAL CONSTRAINTS**	1 1616 **1617**

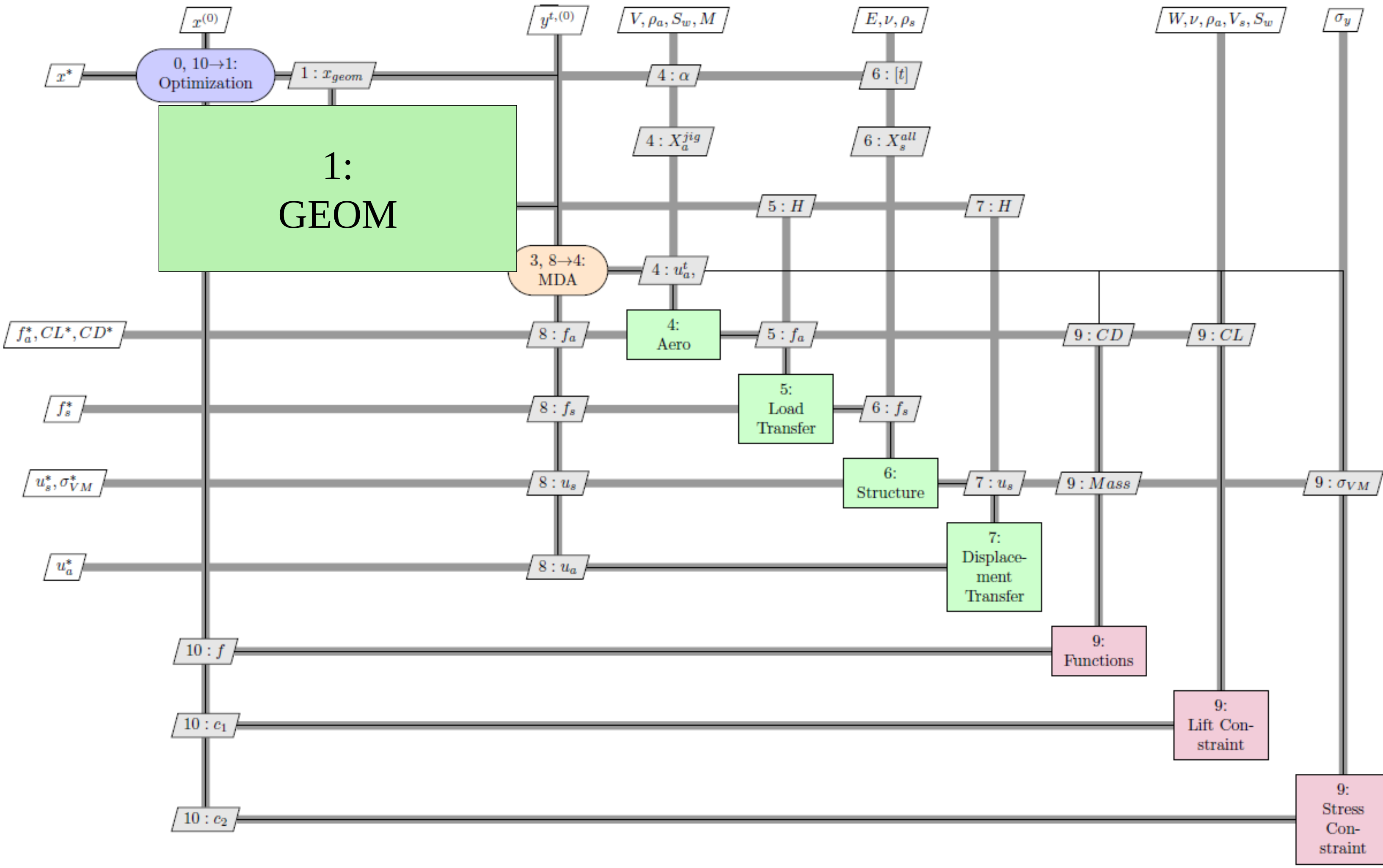
Optimization Problem

XDSM format



Optimization Problem

Geometrical Modeler



Optimization Problem

Geometrical Modeler

Variable Declaration

Inputs=Parameters:
- *Twist Angle*, ϑ
- *Scale Factor*
- *Chord Factor*
- *Sweep Angle*
- *MID Spar position*

Outputs=Unknown:
- *Aero grid points*, X_a
- *Coordinates of the structural nodes*, X_s

Create the Geometry .igs

Create the Structural Mesh .bdf

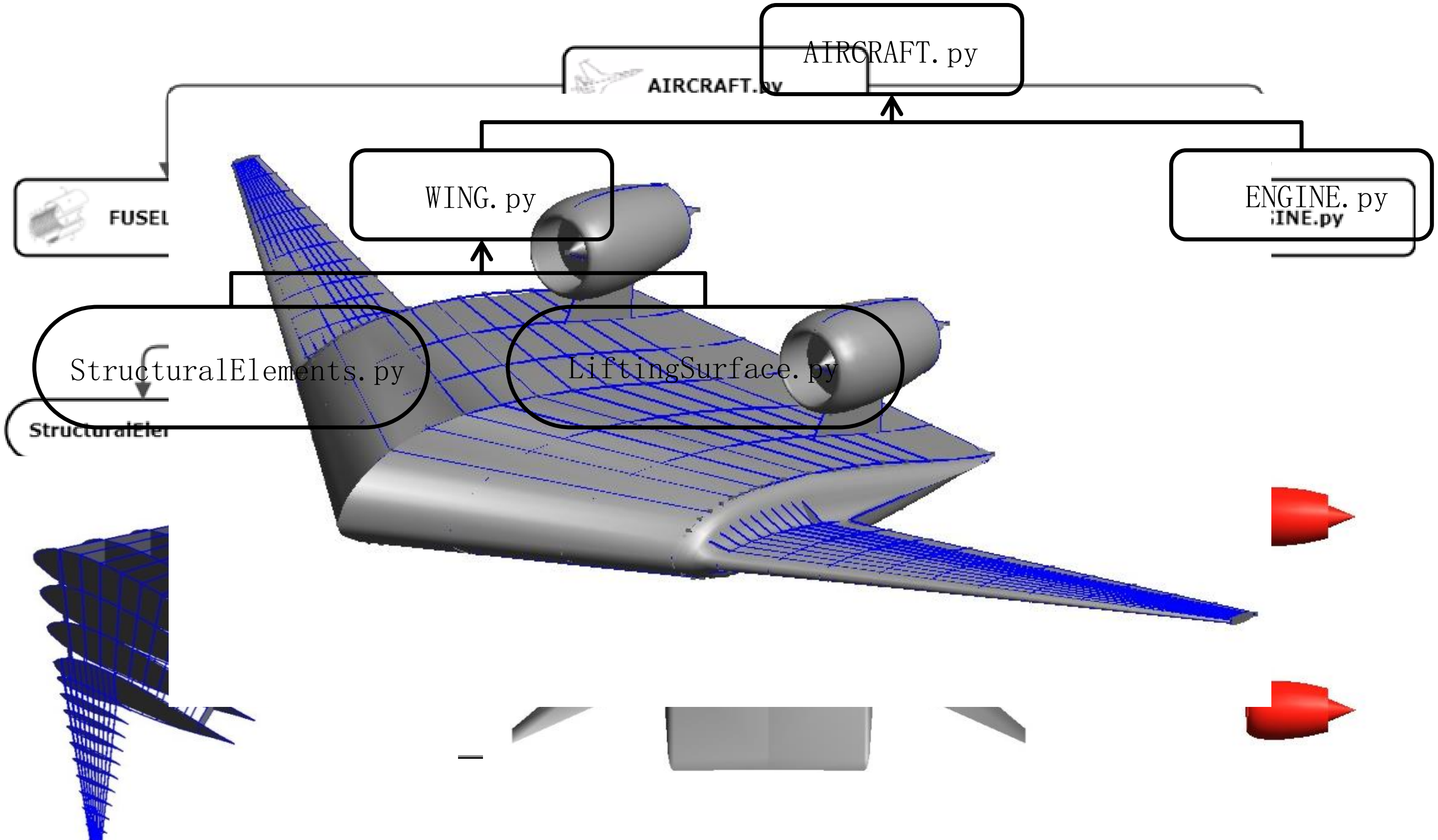
Get the Aero Nodal Coordinates

Get the Struct Nodal Coordinates

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.

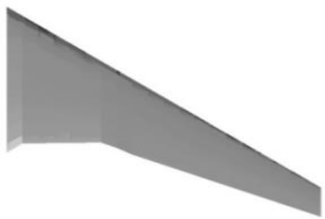
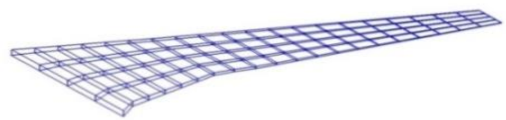
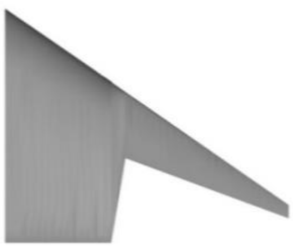
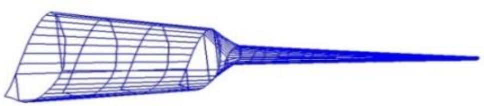
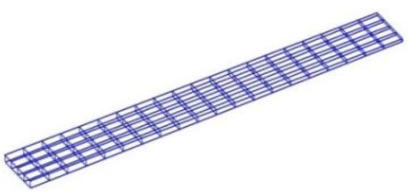


[1] http://occ-airconics.readthedocs.io/en/latest/

Optimization Problem

Geometrical Modeler

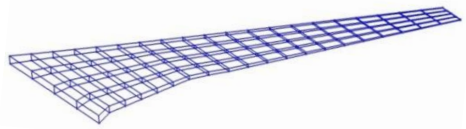
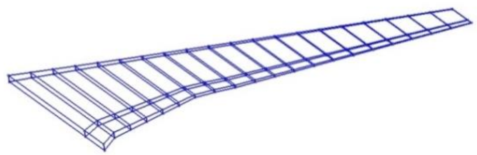
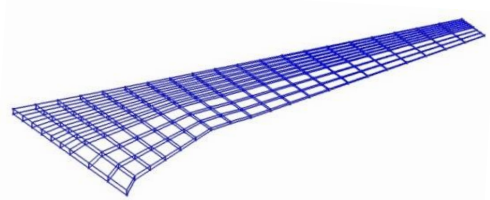
All types of body shape may be reproduced, here some wing examples:

Aerodynamic Surface	Airframe	Wing Type
		CRM
		BWB
		GOLAND

Optimization Problem

Geometrical Modeler

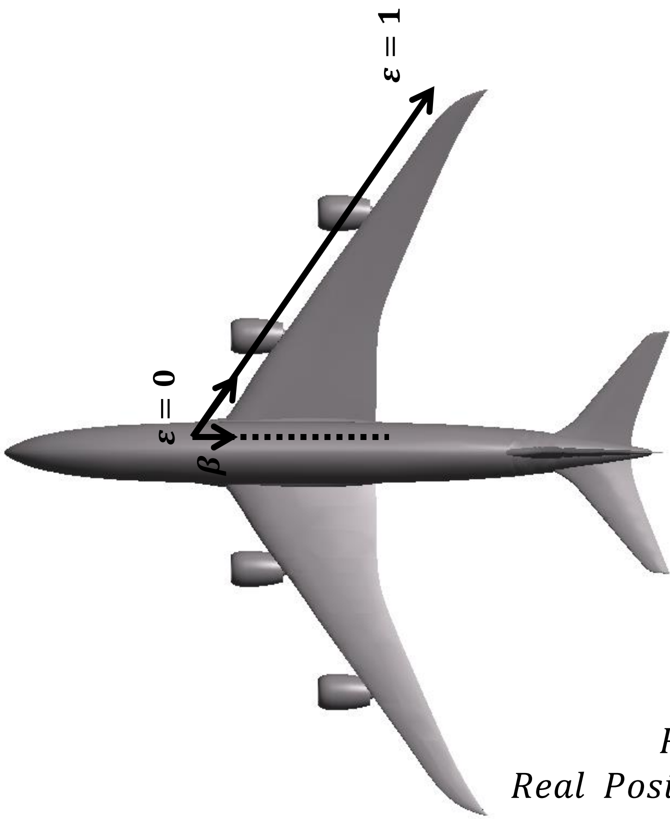
Many types of airframe:

Number of **Ribs**	
Spars Position	
Number and Position of **Stringers**	

Optimization Problem

Geometrical Modeler

Parametrization

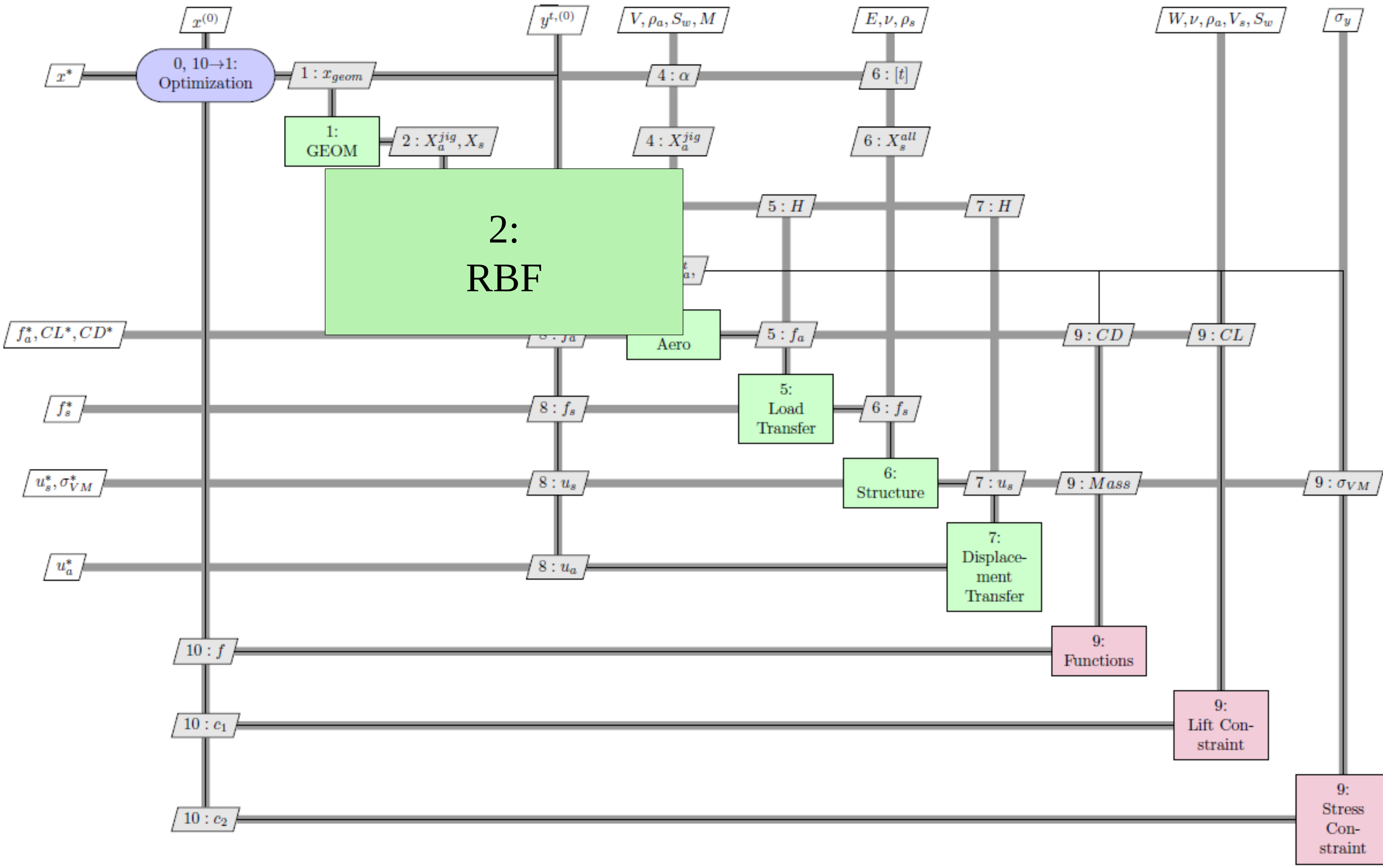


c_n	$\cdots$	$c_1 \; c_2$	***Chord***
d_n	$\cdots$	$d_1 \; d_2$	***Dihedral***
t_n	$\cdots$	$t_1 \; t_2$	***Twist***
s_n	$\cdots$	$s_1 \; s_2$	***Sweep***

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

Optimization Problem

Aerodynamic



Optimization Problem
Interpolation - Radial Basis Function

Variable Declaration

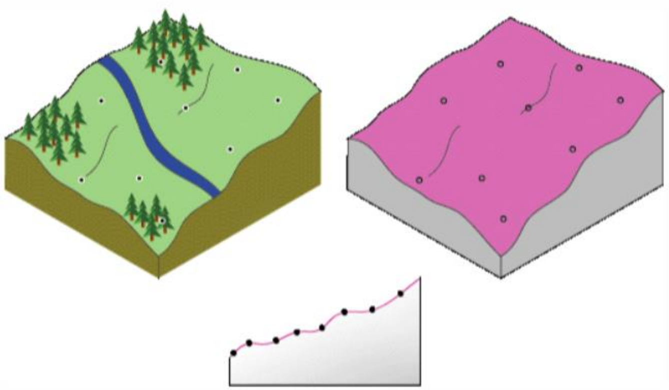
Inputs=Parameters: $\begin{cases} \textit{Aero grid points}, X_a \\ \textit{Coordinates of the structural nodes}, X_s \end{cases}$

Outputs=Unknown: $\{ \textit{Interpolation Matrix}, H$

Solve_nonlinear Method

Radial Basis Function (RBF) for Aero-Struct Nodes Interpolation

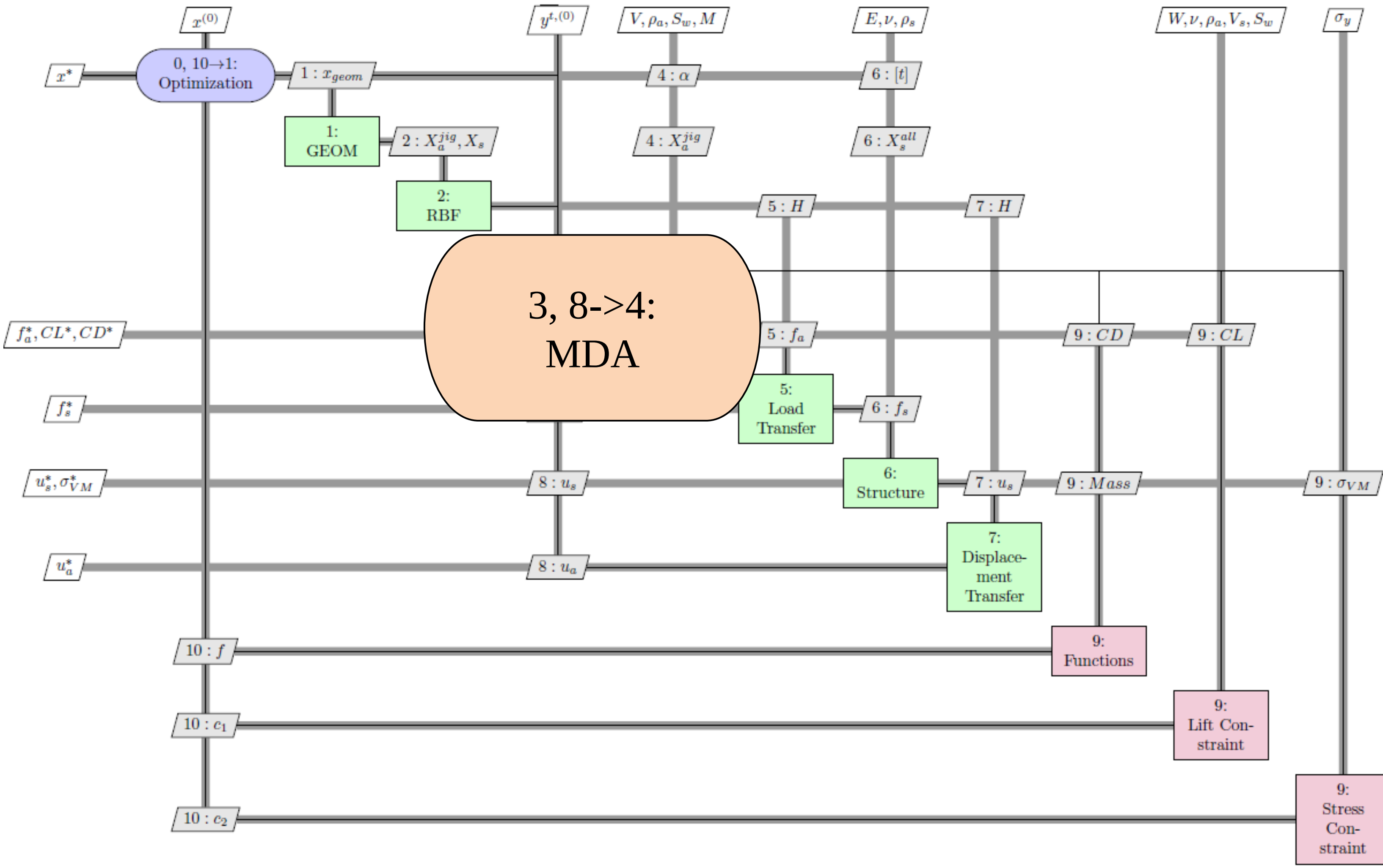
Function Type = Multiquadratic



http://pro.arcgis.com/fr/pro-app/help/analysis/geostatistical-analyst/how-radial-basis-functions-work.htm

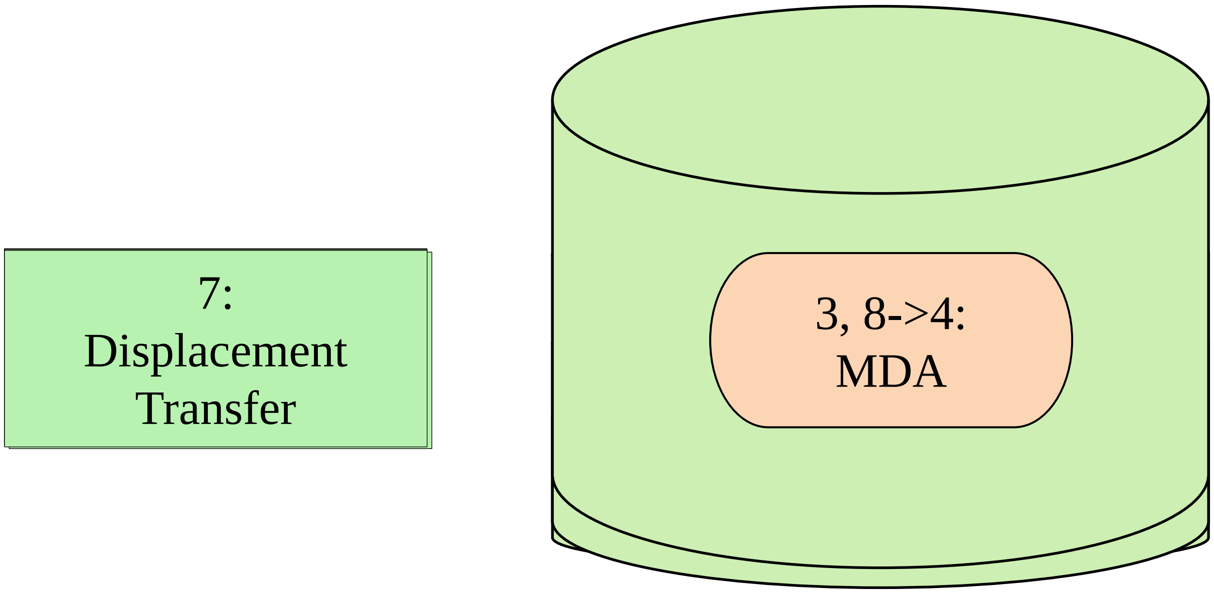
Optimization Problem

MDA Group



Optimization Problem

MDA Group



$$\left.\begin{matrix} f_a \\ f_s \\ u_s \\ u_a \end{matrix}\right\} = unknowns$$

Nonlinear Gauss Seidel solver (default solver for a group)

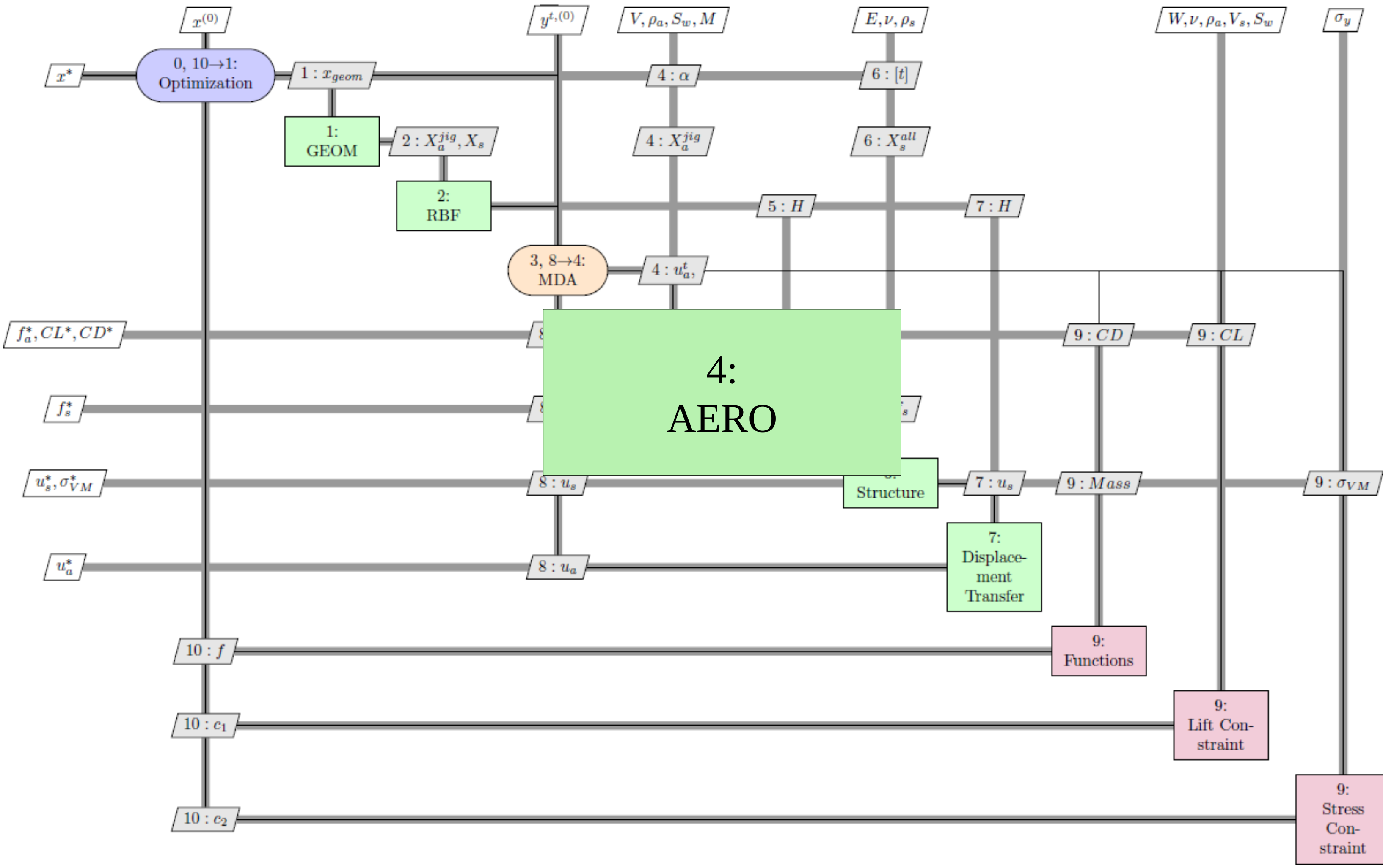
$$p_{k+1} = g_1(p_k, q_k, r_k)$$
$$q_{k+1} = g_2(p_{k+1}, q_k, r_k)$$
$$r_{k+1} = g_3(p_{k+1}, q_{k+1}, r_k)$$

Convergence:

$$if\ iter\_count > \max iteration\ \boldsymbol{or}\ \frac{\|unknown_{k+1} - unknown_k\|}{\|unknown_{k+1}\|} \leq r_{utol}$$

Optimization Problem

Aerodynamic



Optimization Problem

Aerodynamic

Run the Aerodynamic Analisys

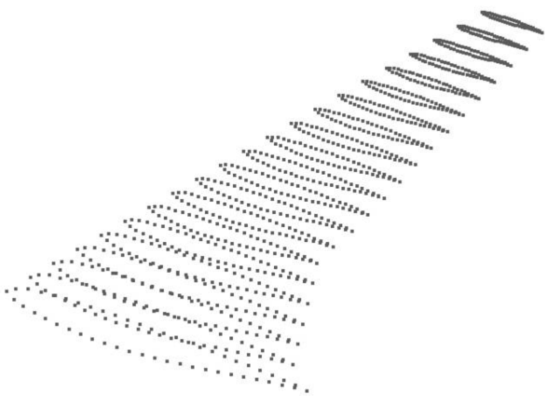
Create the Current Geometry

Variable Declaration

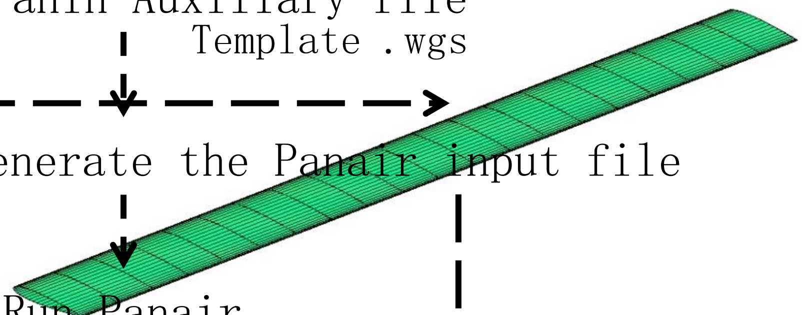
Create a Panin Auxiliary file

Template .wgs

Aero grid point, $\boldsymbol{X_a}$



Execute Panin to generate the Panair input file



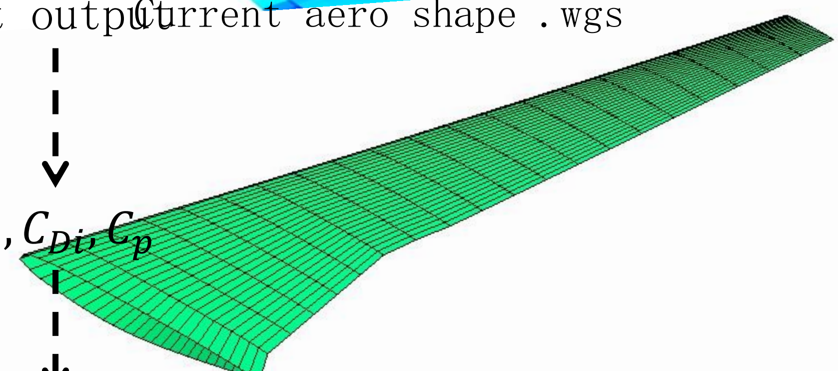
Run Panair

Angle of attack, α

Wing span

Get output

Current aero shape .wgs



\+

Outputs=Unknown:

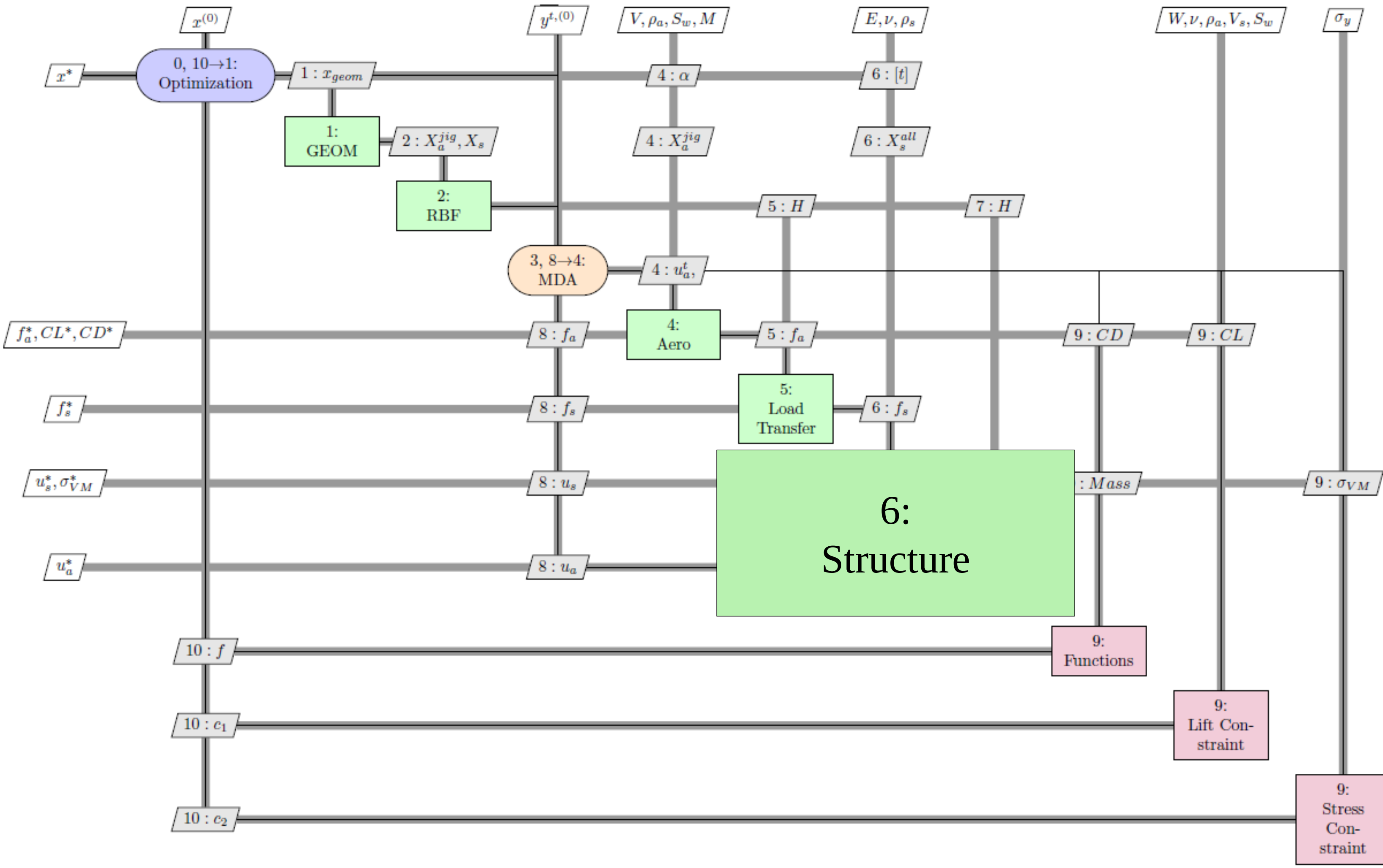
Delta displacements

(evaluated from the Displacement Transfer component)

C_L, C_{Di}, C_p

$$f_a = 0.5 * V^2 * S_w * [vector\ of\ the\ 4\ vertex\ force\ coefficient]$$

Optimization Problem
Structure



openMDAO

Optimization Problem

Structure

Nastran95 Template

Variable Declaration

Pre-prepared .bdf (.inp for Nastran95), anchored to a fixed number of elements, where the GRID POINTS coordinates, the FORCES values, the MATERIAL PROPERTIES, the SPARS THICKNESS and the STRINGERS AREA are kept open.

```
$Shell properties
PSHELL,1417,30,{t1},30,,30
PSHELL,1418,30,{t2},30,,30
PSHELL,1419,30,{t3},30,,30
PSHELL,1420,30,{t4},30,,30
PSHELL,1421,30,{t5},30,,30
PSHELL,1422,30,{t6},30,,30
PSHELL,1423,30,{t7},30,,30
PSHELL,1424,30,{t8},30,,30
PSHELL,1425,30,{t9},30,,30
PSHELL,1426,30,{t10},30,,30
PSHELL,1427,30,{t11},30,,30
PSHELL,1428,30,{t12},30,,30
PSHELL,1429,30,{t13},30,,30
PSHELL,1430,30,{t14},30,,30
PSHELL,1431,30,{t15},30,,30
PSHELL,1432,30,{t16},30,,30
PSHELL,1433,30,{t17},30,,30

$Rod properties
PROD,1434,30,{s1}

MAT1,30,{E},,{nu},{rho_s}
PARAM,AUTOSPC,1
```

```
des
,{Fz1}
,{Fz2}
,{Fz3}
,{Fz4}
,{Fz5}
,{Fz6}
,{Fz7}
,{Fz8}
,{Fz9}
```

Force on the outer surface nodes, f_s

Coordinates of the structural nodes, X_s

Vector of the spars thickness, t

Vector of the stringers cross section, s

Young Modulus, E

Poisson ratio, nu

Material density, ρ

Coordinates of the structural nodes, X_s

$t, s,$ *Material Properties*

Displacements of the nodes of the outer surface, u_s

Von Mises Stress

Forces on the outer surface nodes, f_s

Mass

Optimization Problem

Structure

Create Nastran95 input file

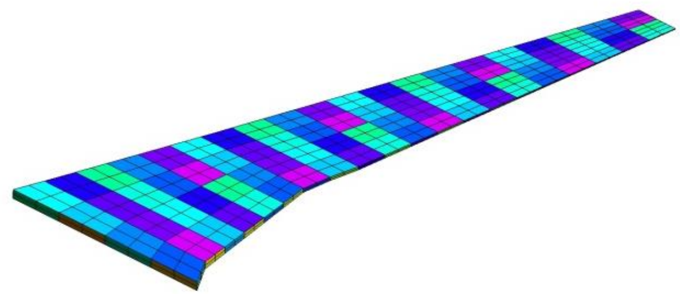
↓

Run Nastran95

↓

Get output data

(read the .pnh file for displacements and stress, read the .out for Mass)

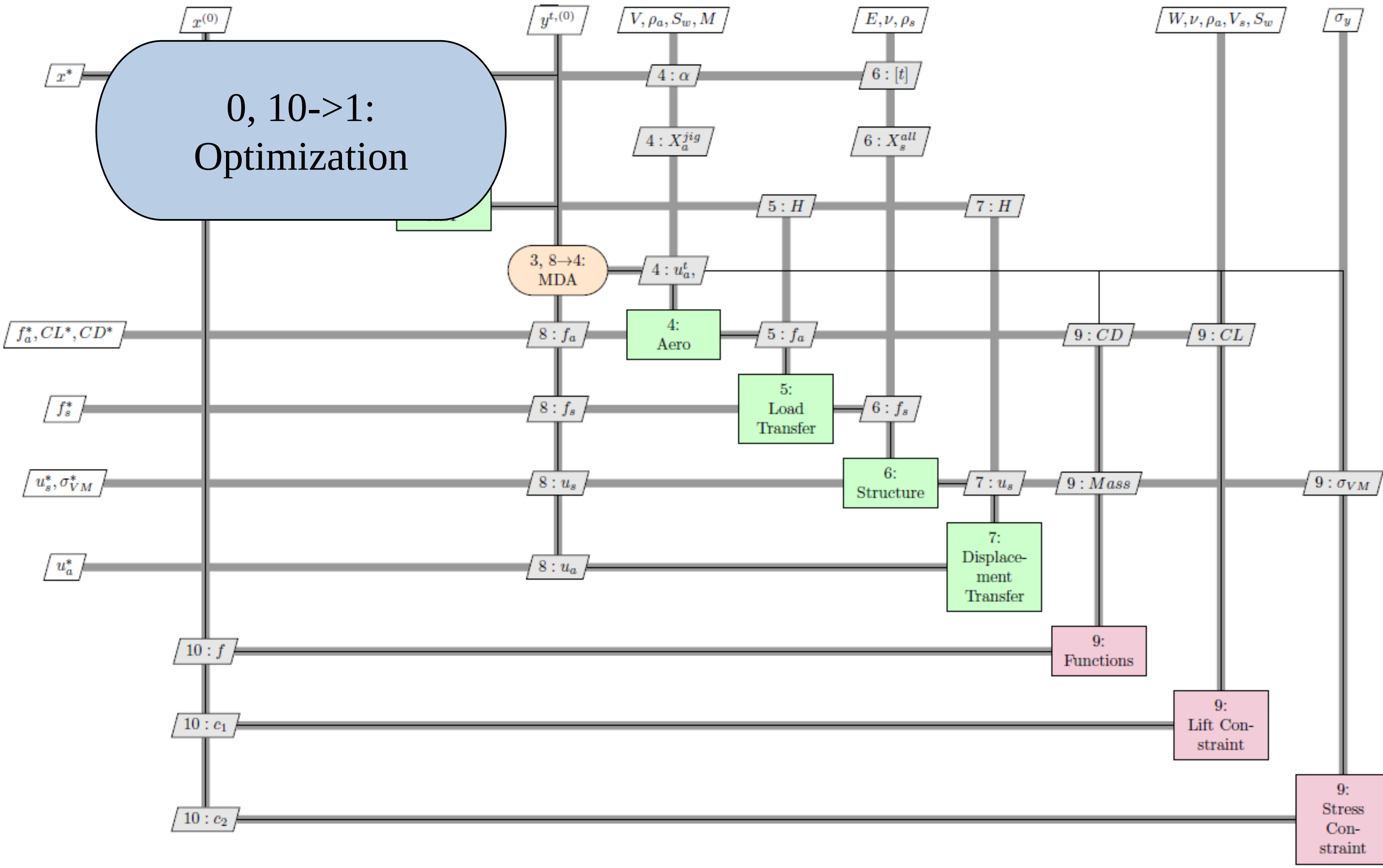


$$\boldsymbol{u_s = nodal\ dispacement\ vector} \qquad \boldsymbol{M = Mass} \qquad \boldsymbol{\sigma_{VM\_rod} = |\sigma_1|}$$

$$\boldsymbol{\sigma_{VM\_shell} = \sqrt{\sigma^2{}_{11} - \sigma_{11}\sigma_{22} + \sigma^2{}_{22}}}$$

Optimization Problem

Function



Optimization Problem

Constraints

Lift Constraint

Steady Flight L=W, Lift generated by the CRM at the nominal cruise condition of M = 0.85, CL = 0.5 at 37 000 ft.

$$CL - 0{,}5 * \rho_a * V^2 * S_w = 0$$

Stress Constraint

$$\sigma_{VM} - \sigma_{yield} \leq 0$$

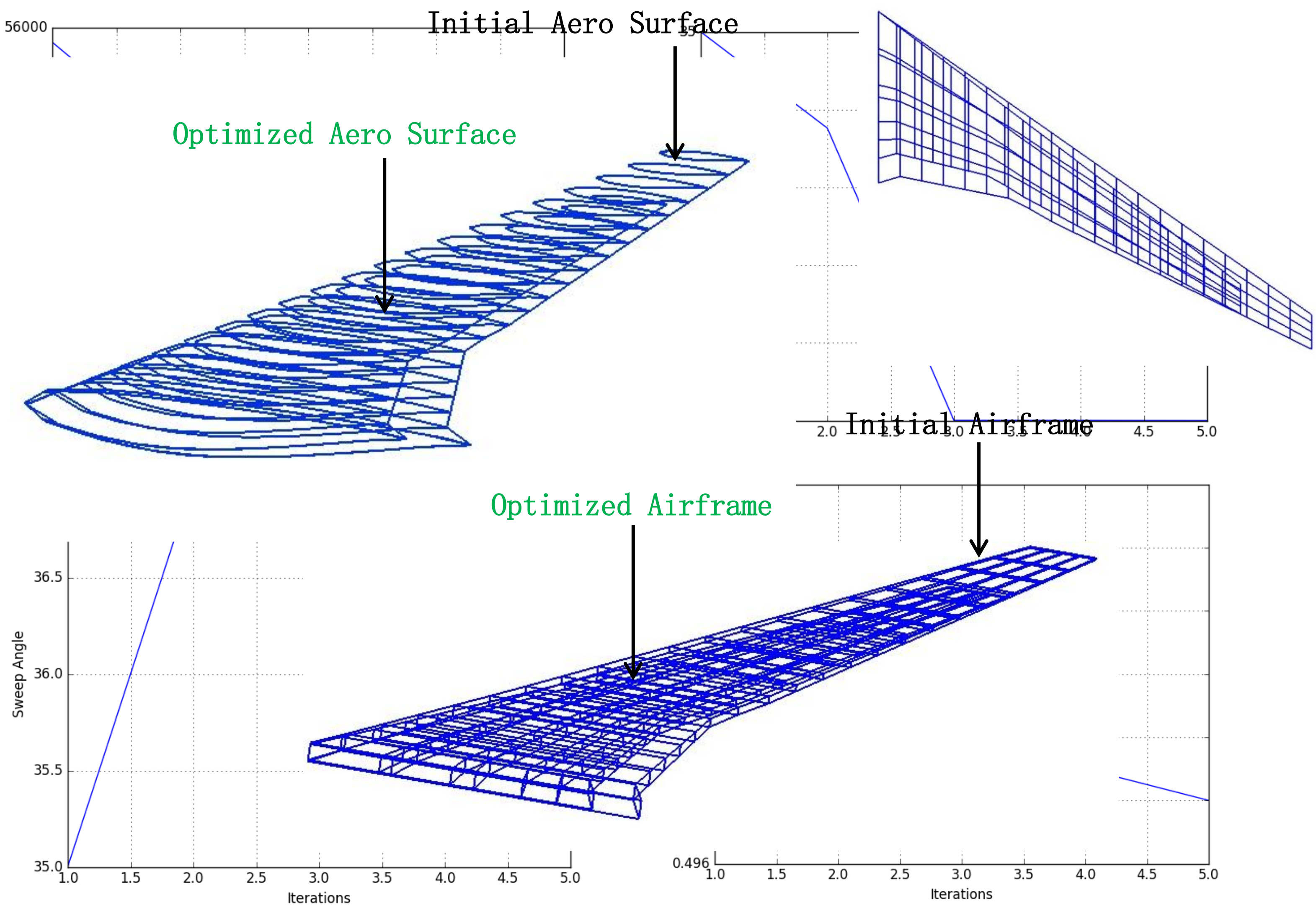
Constrained Optimizer

Scipy Library:'COBYLA', 'SLSQP'

Optimization Problem

Results: 3D Model

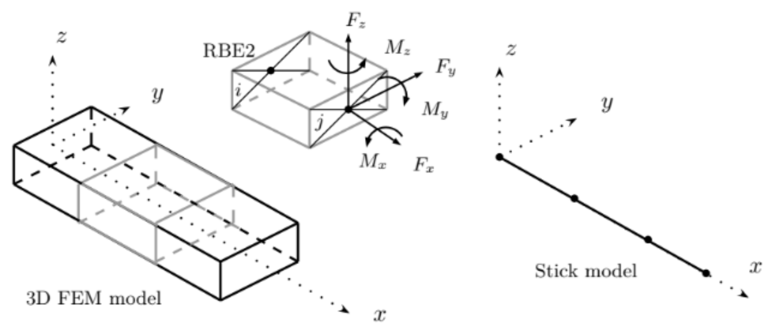
Minimize M with respect to the **scale factor** and the **sweep angle**



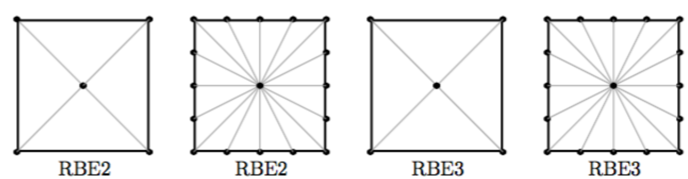
Optimization Problem

Results: Reduced Model

Stick Model generation:



Non Structural Elements Selection:

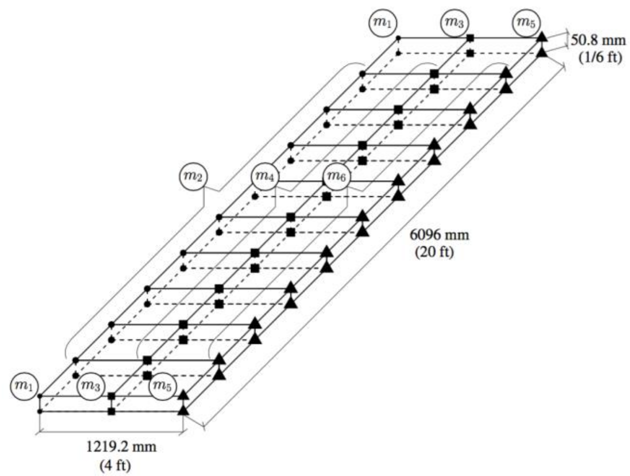


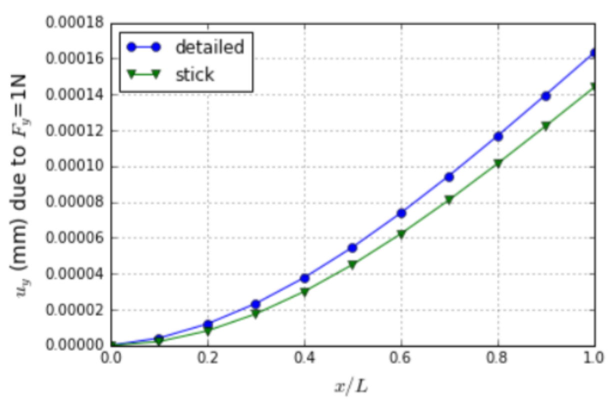
Link	RBE2 corners	RBE2 all section	RBE3 corners	RBE3 all section	Exact
$A(\mathrm{mm}^2)$	457.40	501.36	454.05	497.17	480
$I_y(\mathrm{mm}^4)$	301788.23	321151.85	5830.79	5040.02	288320
$I_z(\mathrm{mm}^4)$	301788.23	321151.85	5830.78	5040.01	288320
$J(\mathrm{mm}^4)$	471419.48	477490.78	58848.16	369341.18	440223.8

Optimization Problem

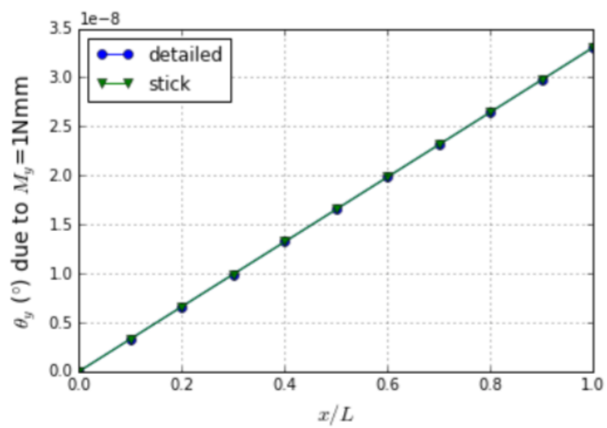
Results: Reduced Model

Static Results of the Reduced Model:





(c) Horizontal displacement u_y due to F_y=1 N.

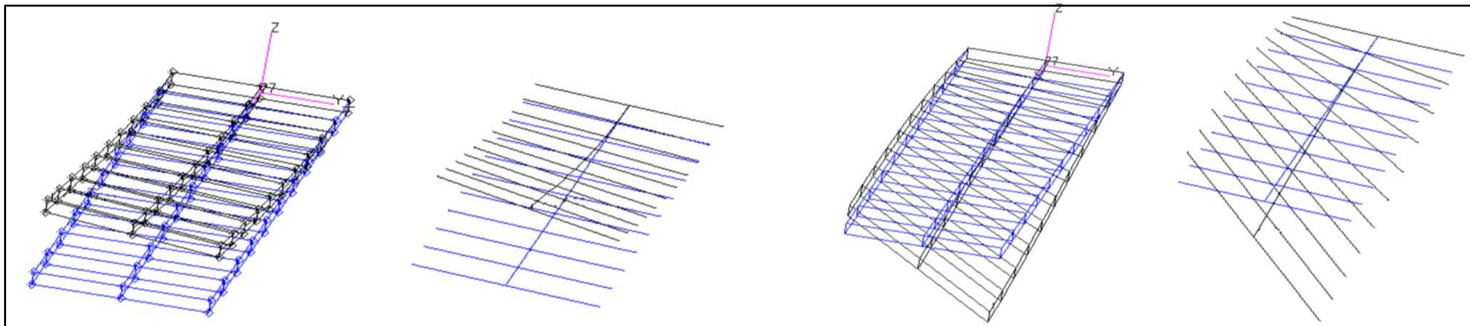


(d) Horizontal rotation θ_y due to M_y=1 N mm.

Optimization Problem

Results: Reduced Model

Dynamic Results of the Reduced Model:



(a) 3D model, $f = 1.98$ Hz (b) stick model, $f = 1.96$ Hz (a) 3D model, $f = 4.05$ Hz (b) stick model, $f = 3.98$ Hz

Mode	detailed (Hz)	stick (Hz)	error (%)	corrected (Hz)	error (%)
1	1.98	2.07	4.55	1.96	1.01
2	4.05	4.69	15.80	3.98	1.73
3	9.69	10.87	12.18	9.69	0.00
4	13.29	14.69	10.53	13.88	4.44
5	13.49	15.44	14.46	14.04	4.08
6	18.00	20.25	12.50	17.30	3.89
7	23.88	27.37	14.61	23.26	2.60
8	29.93	33.64	12.40	28.81	3.74
9	31.12	34.90	12.15	32.24	3.60
10	35.09	39.73	13.22	33.75	3.82

Thank you for your ATTENTION!