Setup and Validation of High Fidelity Aeroelastic Analysis Methods Based on RBF Mesh Morphing

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Research framework

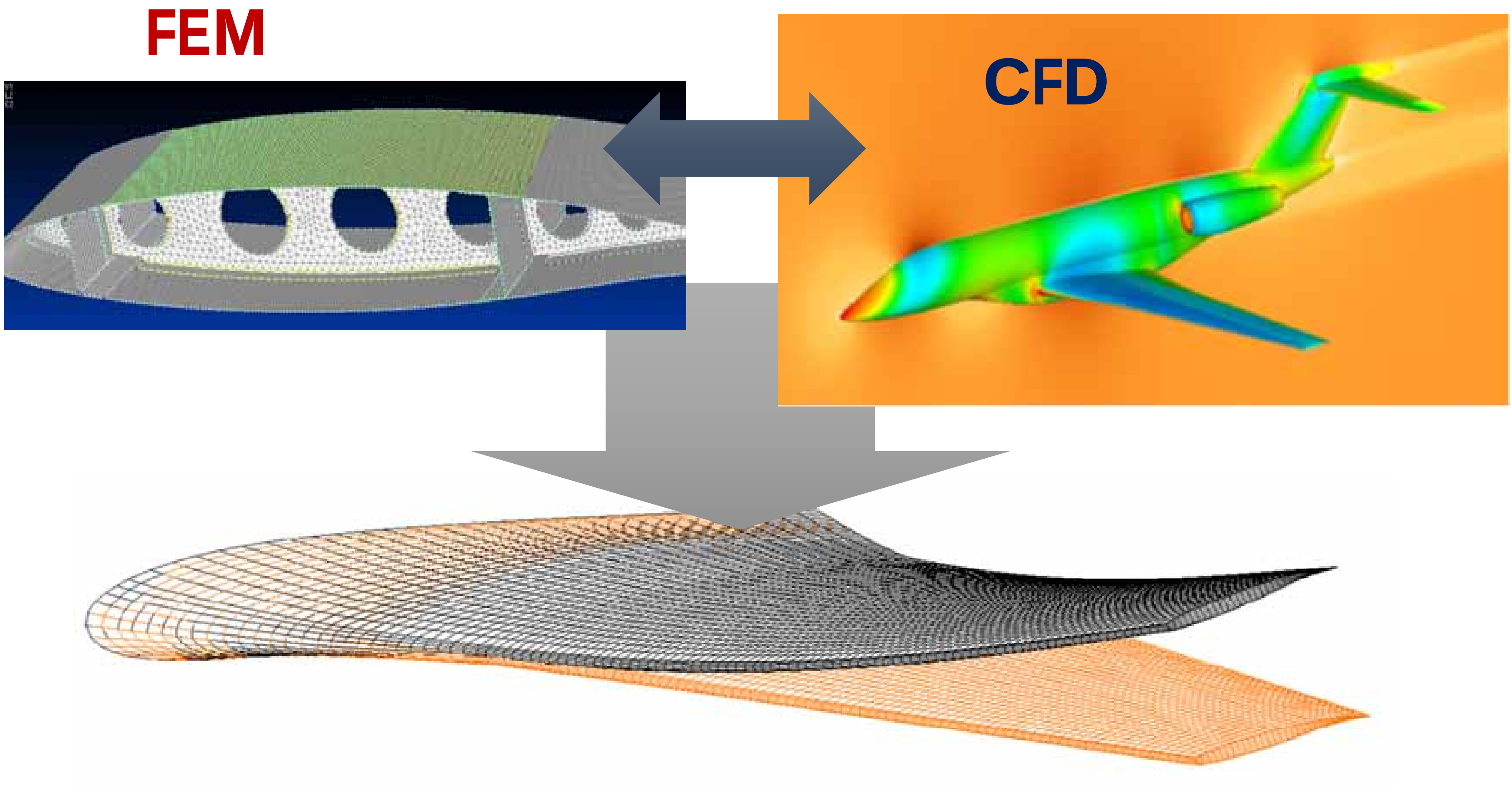
RIBES

RBF4AERO

CLEANSKY

GreenRegionalAircraft

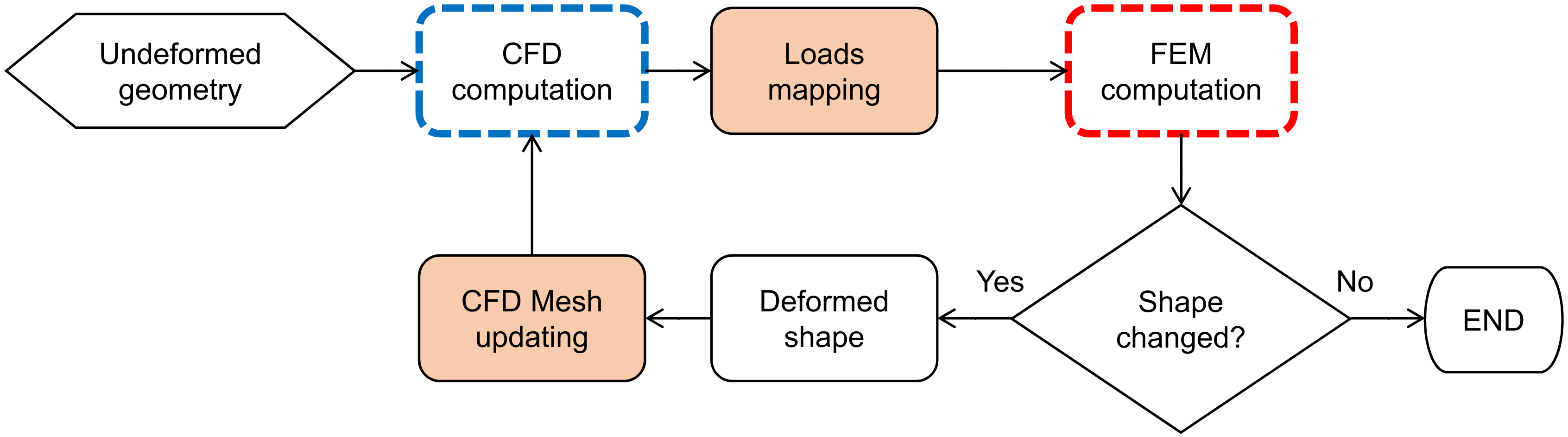
High fidelity FSI analyses



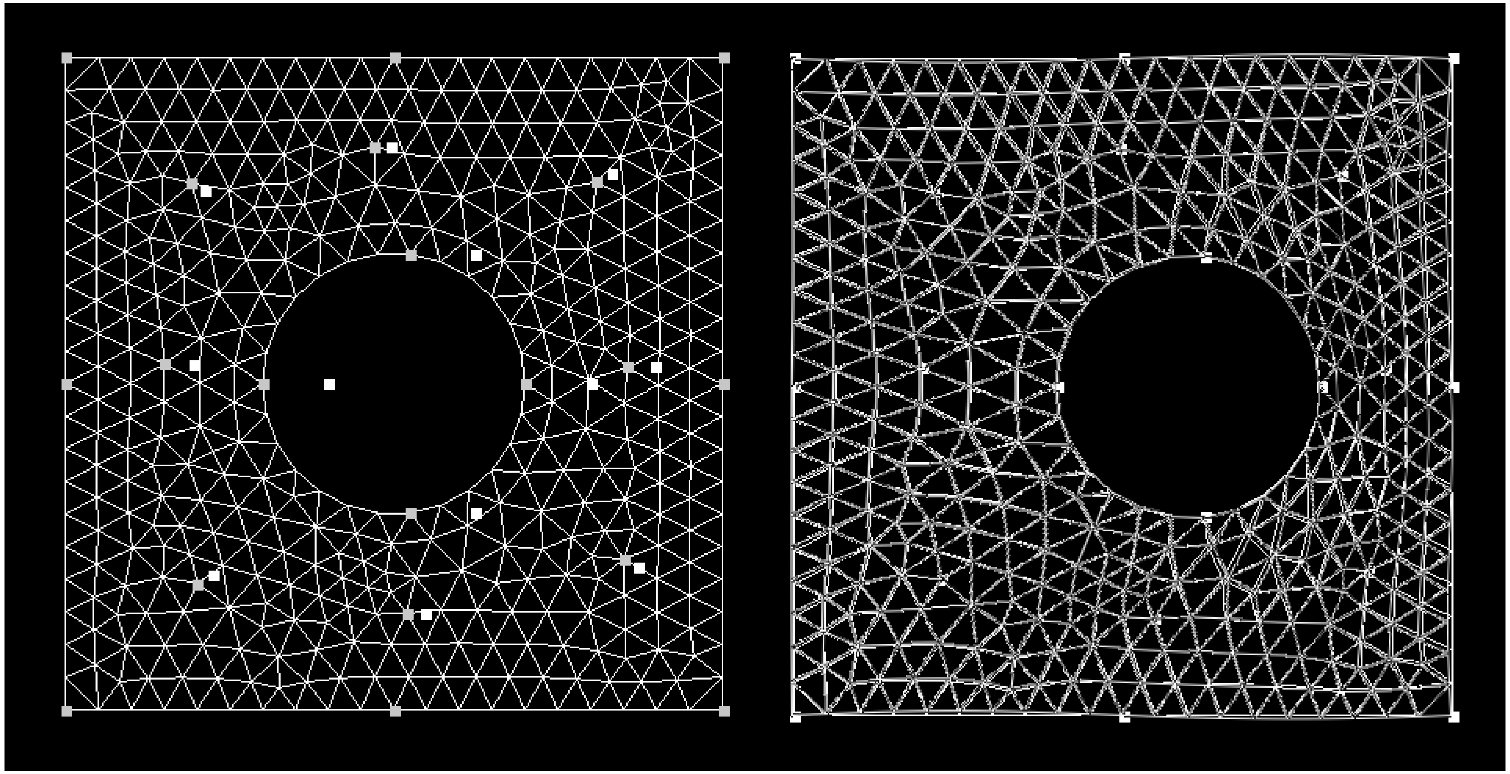
Overview of the work

- Setup of FSI analysis methods
  - 2-way (CFD-CSM) coupling
  - Modal approach for aeroelastic analyses
- Validation against experiments
  - Piaggio P1XX aircraft (transonic)
  - RIBES wing (subsonic)

2 ways FSI procedure

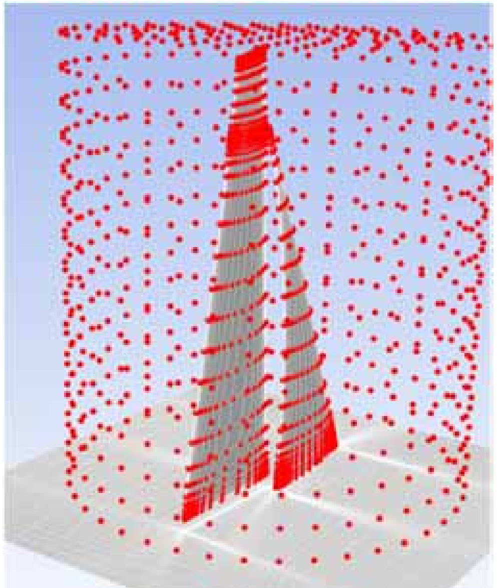


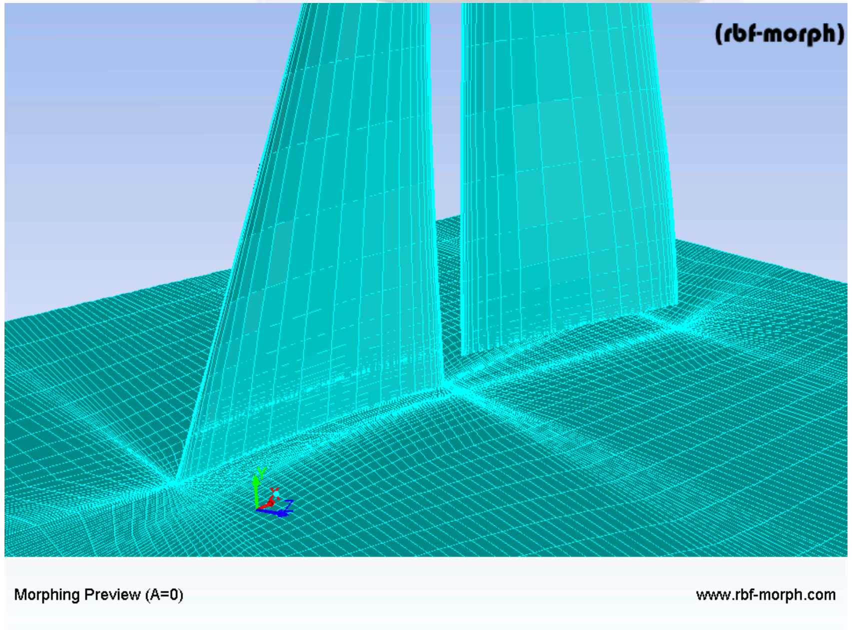
Mesh morphing



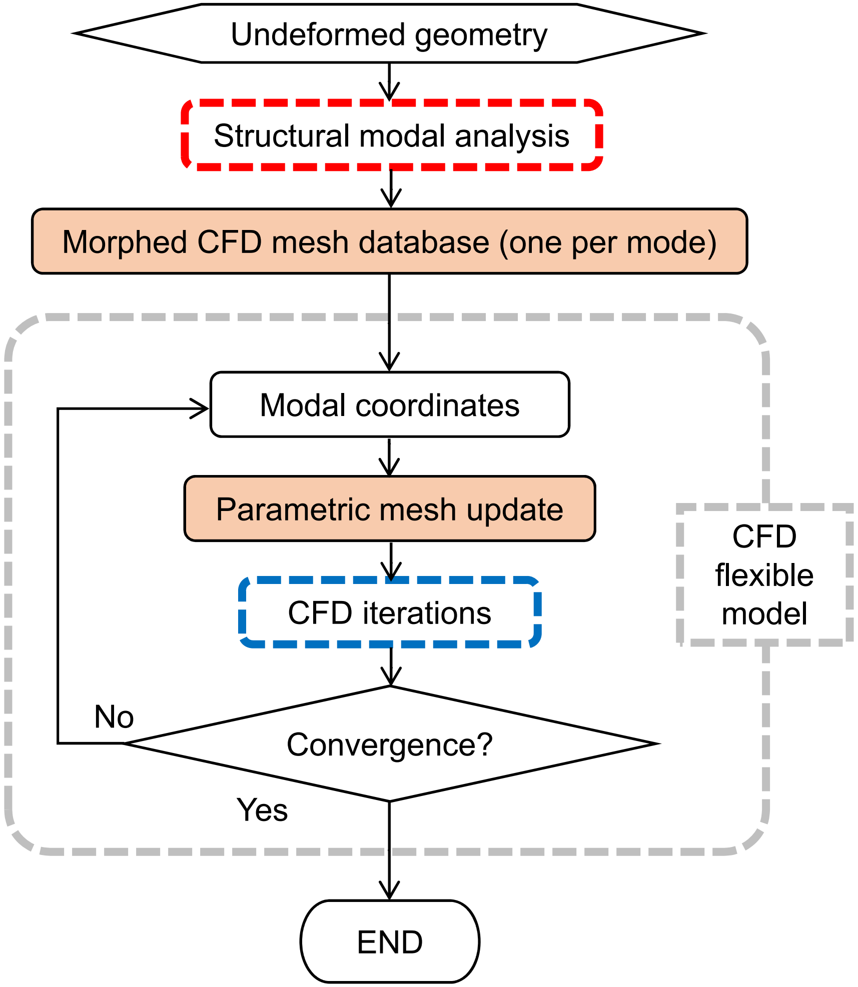
RBF Morph tool

- Setup
  - Select fixed and moving walls by source points
  - Prescribe the displacements (or a combination of)
- Fitting
  - Solving the RBF system and storing the solution
- Smoothing
  - Application of the morphing action on surfaces and volume





Modal approach for FSI



Parametric mesh formulation

number of natural modes

nodal modes displacement

$$X_{CFD} = X_{CFD_0} + \sum_{i=1}^{k} q_i \Delta X_i$$

modal coordinate

Advantages and limits

- Main advantages
  - simpler numerical environments respect 2-way
  - Higher robustness
  - Mesh adaptation during computation (faster solution)
- Limits
  - Linear problems only (small displacements)
  - Uncertainness on the modal base dimension

Piaggio P1XX

Ubaldo Cella

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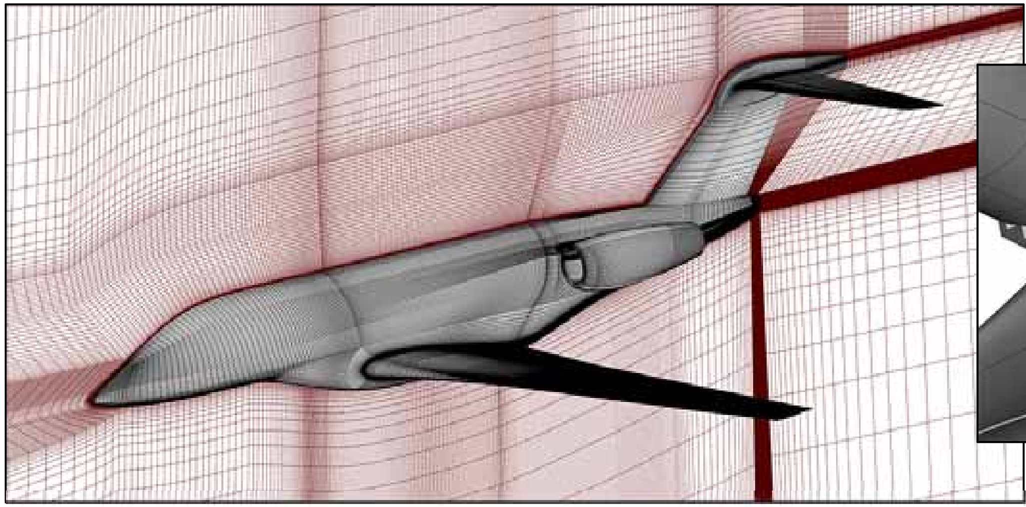
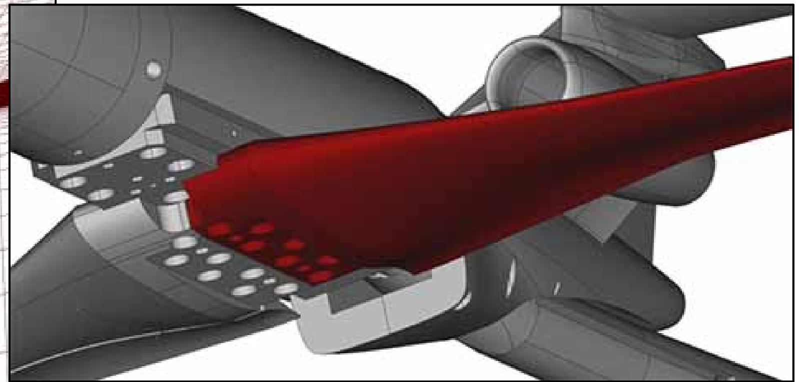
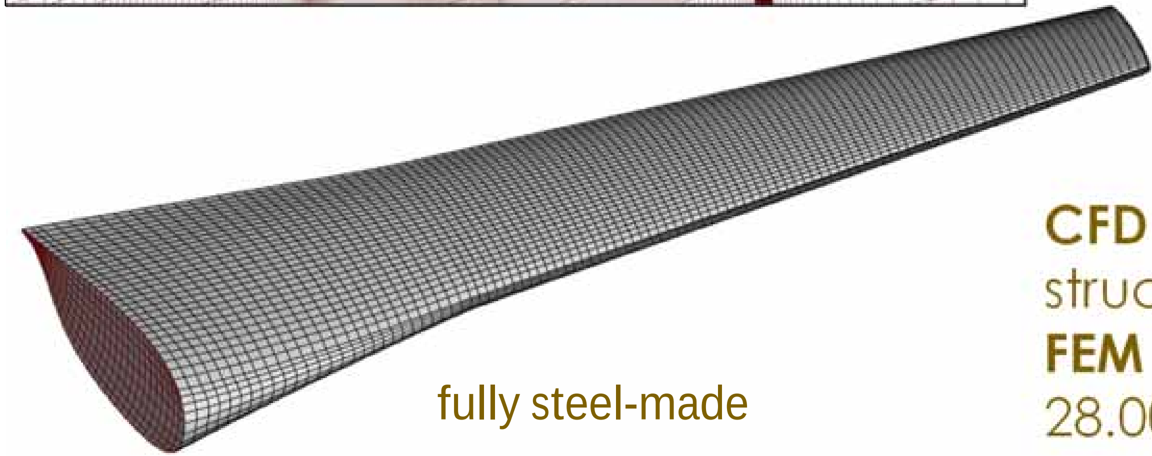
Computational domains



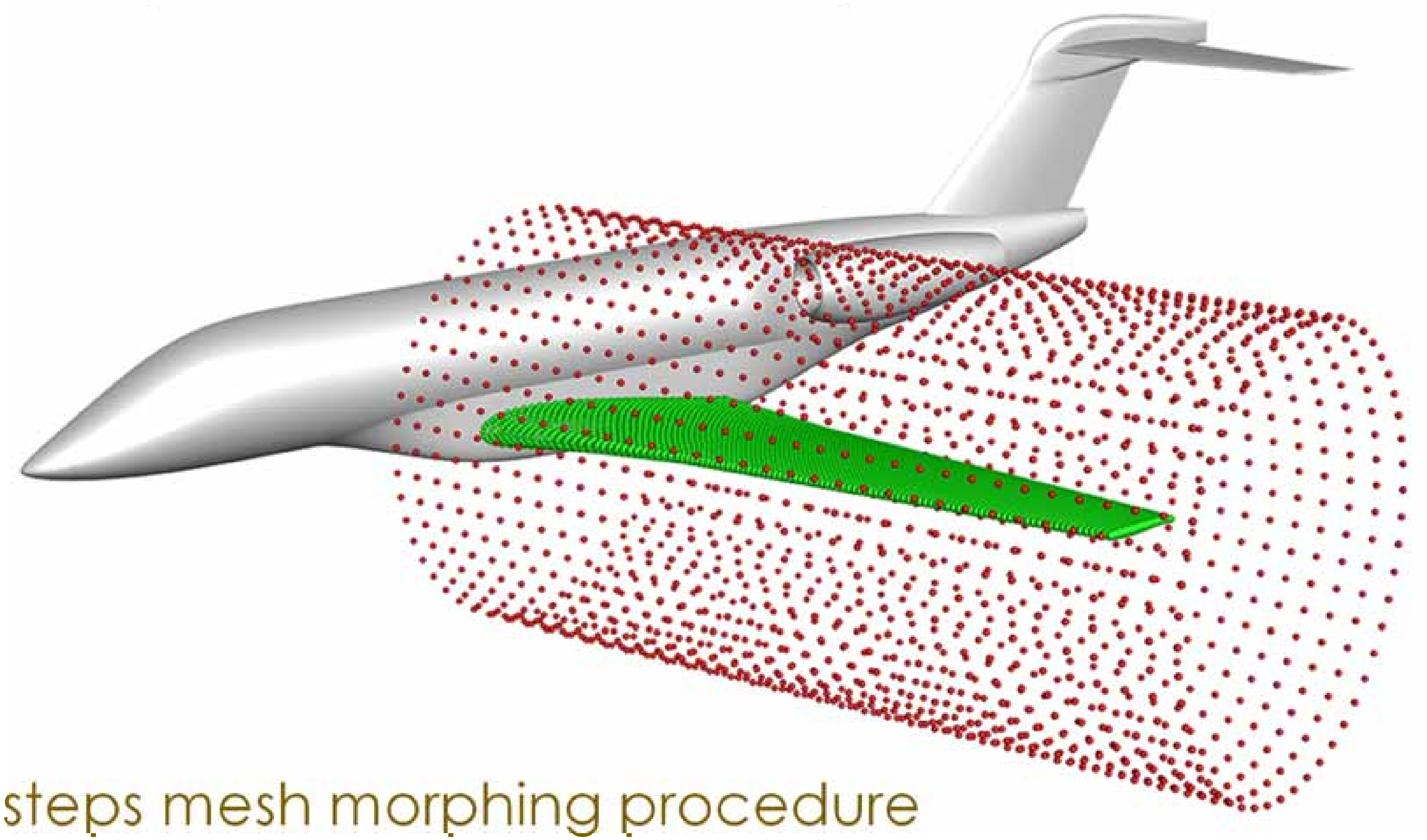




fully steel-made

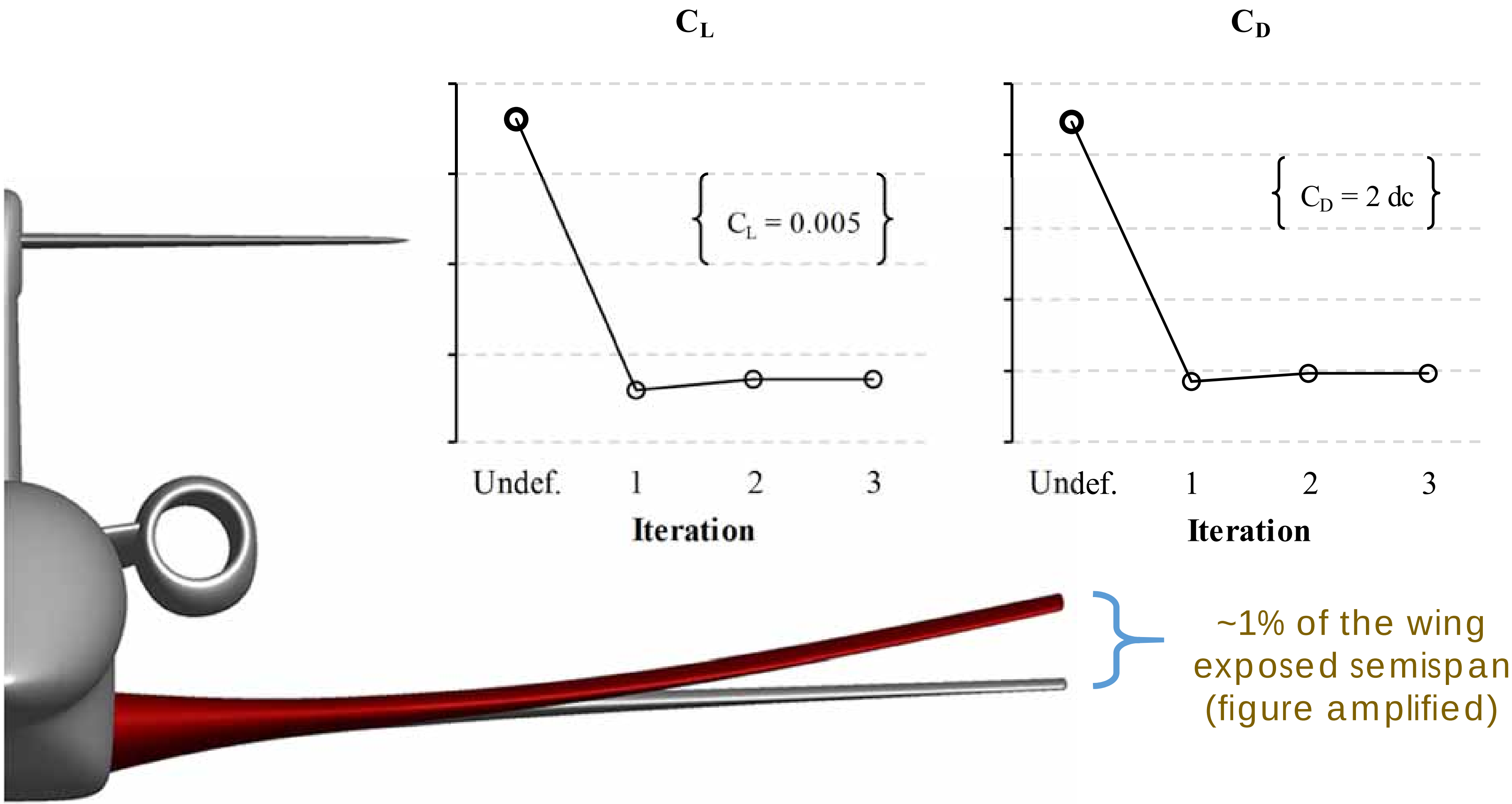
CFD mesh
structured 14 mill. Cells
FEM mesh
28.000 hexa elements

RBF problem setup

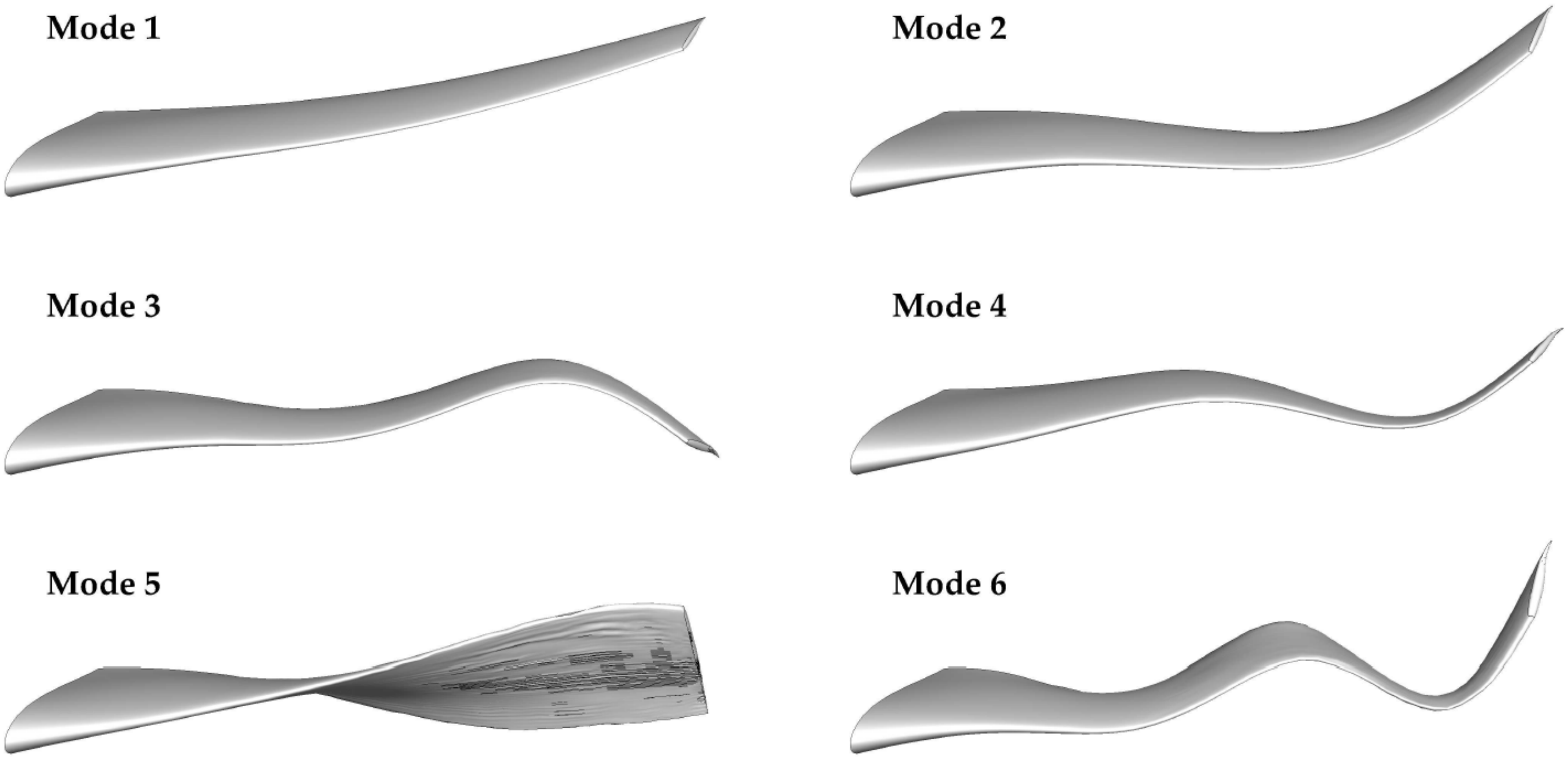


2 steps mesh morphing procedure

2-ways convergence hist.

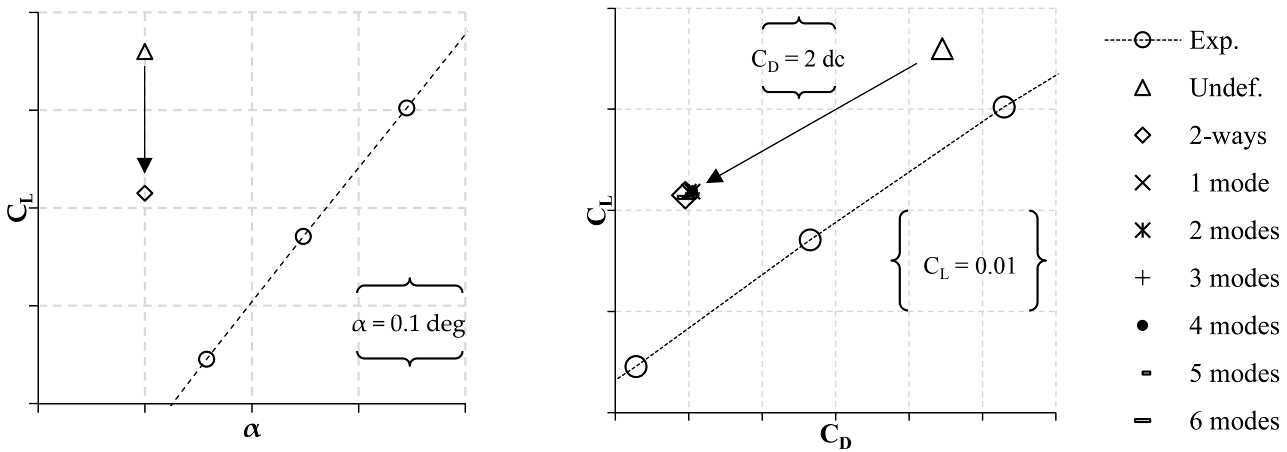


Modal shapes

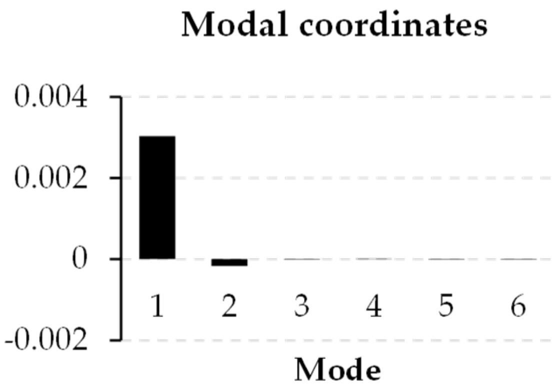


Modal base composed with up to 6 modes

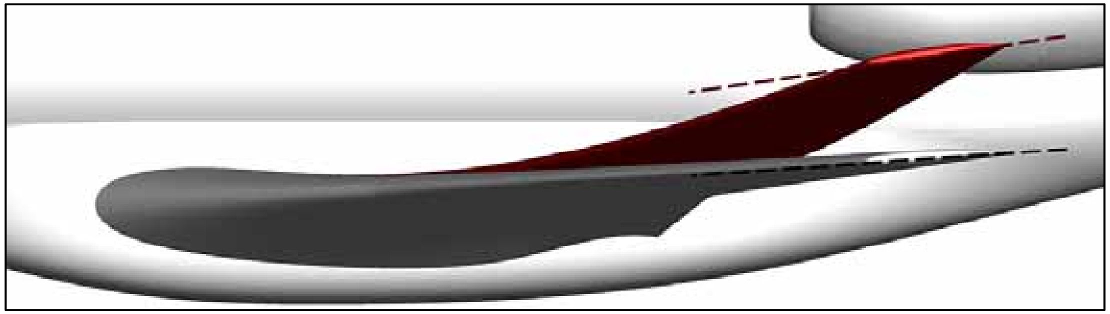
Solutions comparison

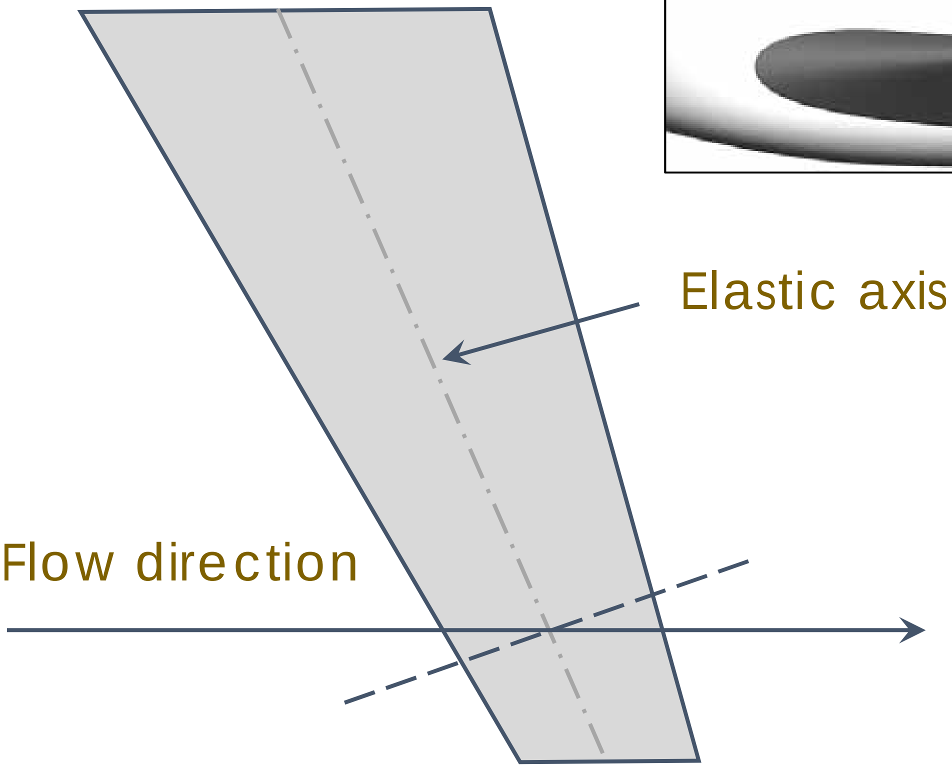


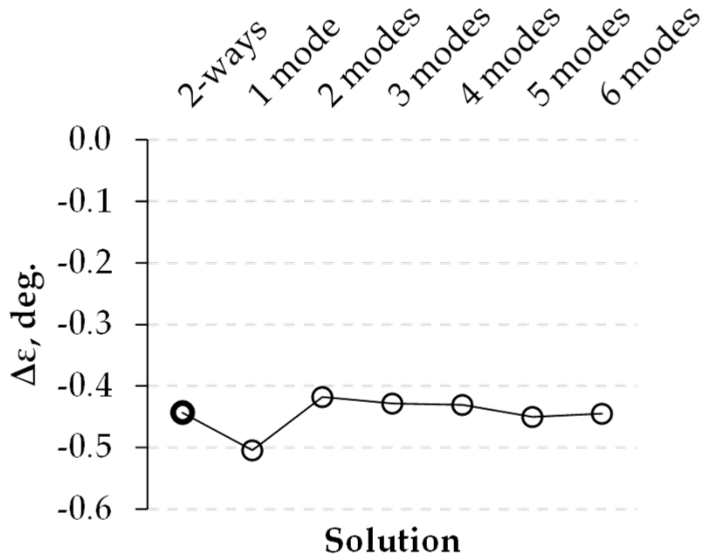
Mach 0.8



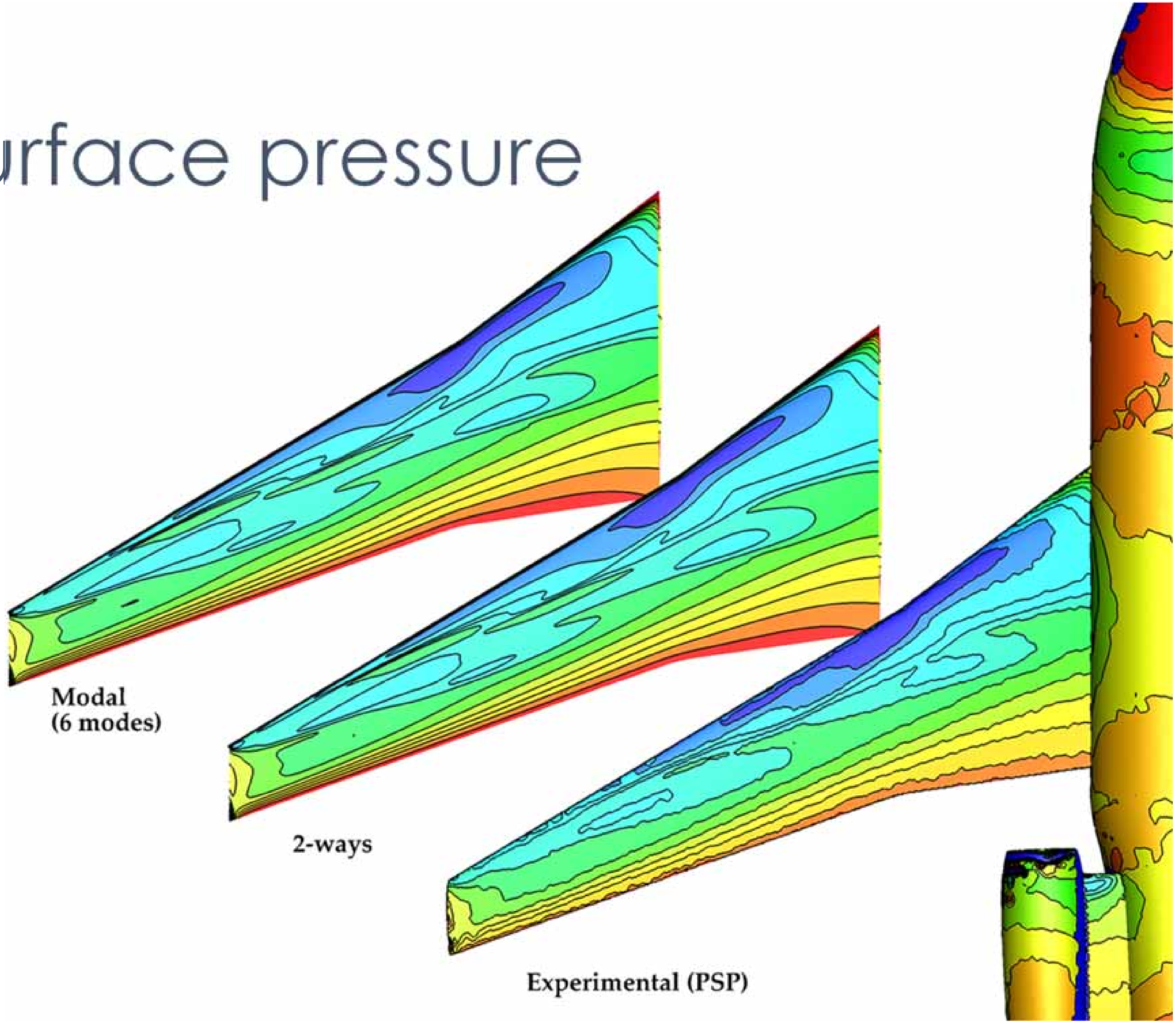
Aero-structure coupling



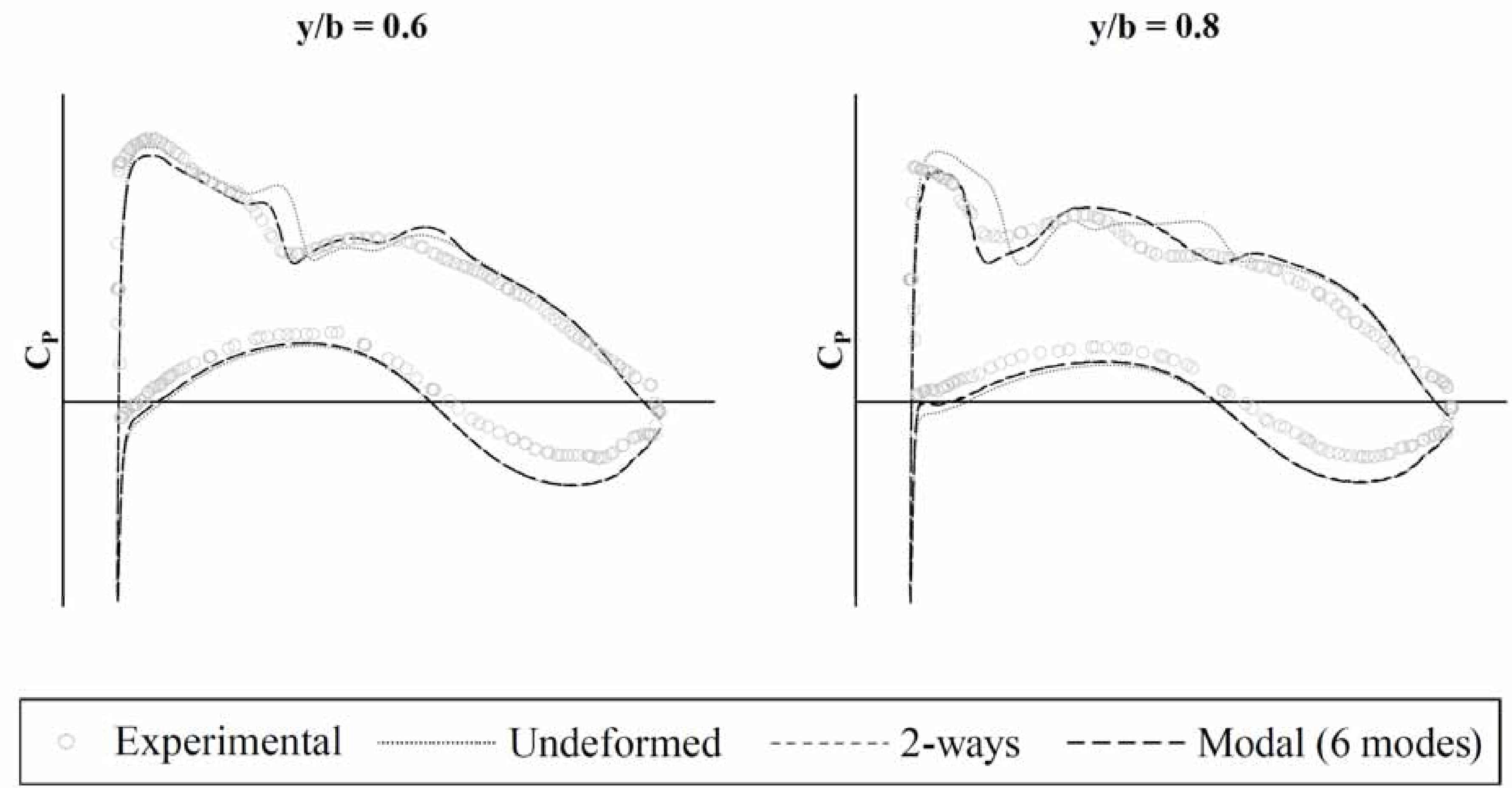




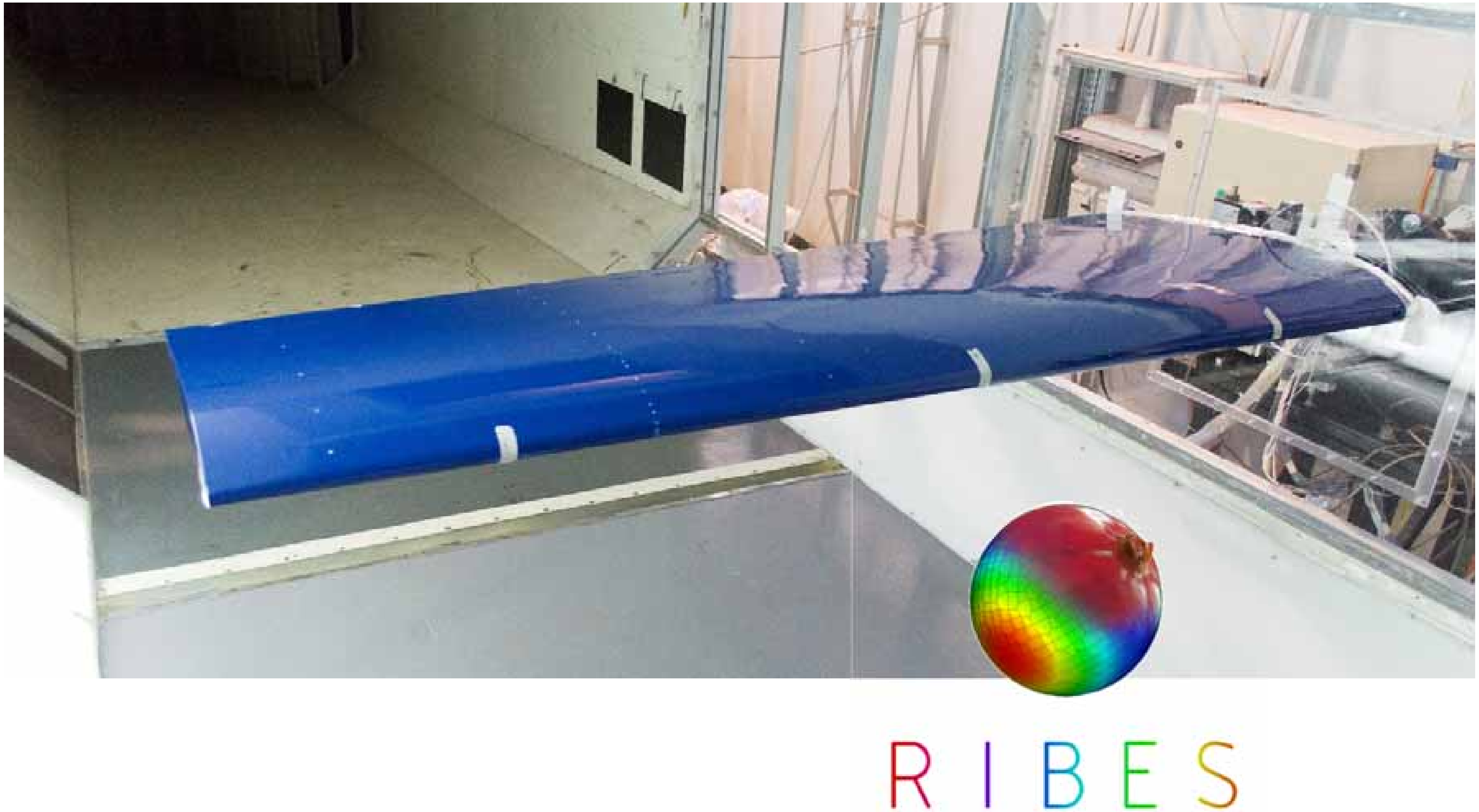
Surface pressure



Pressure comparison



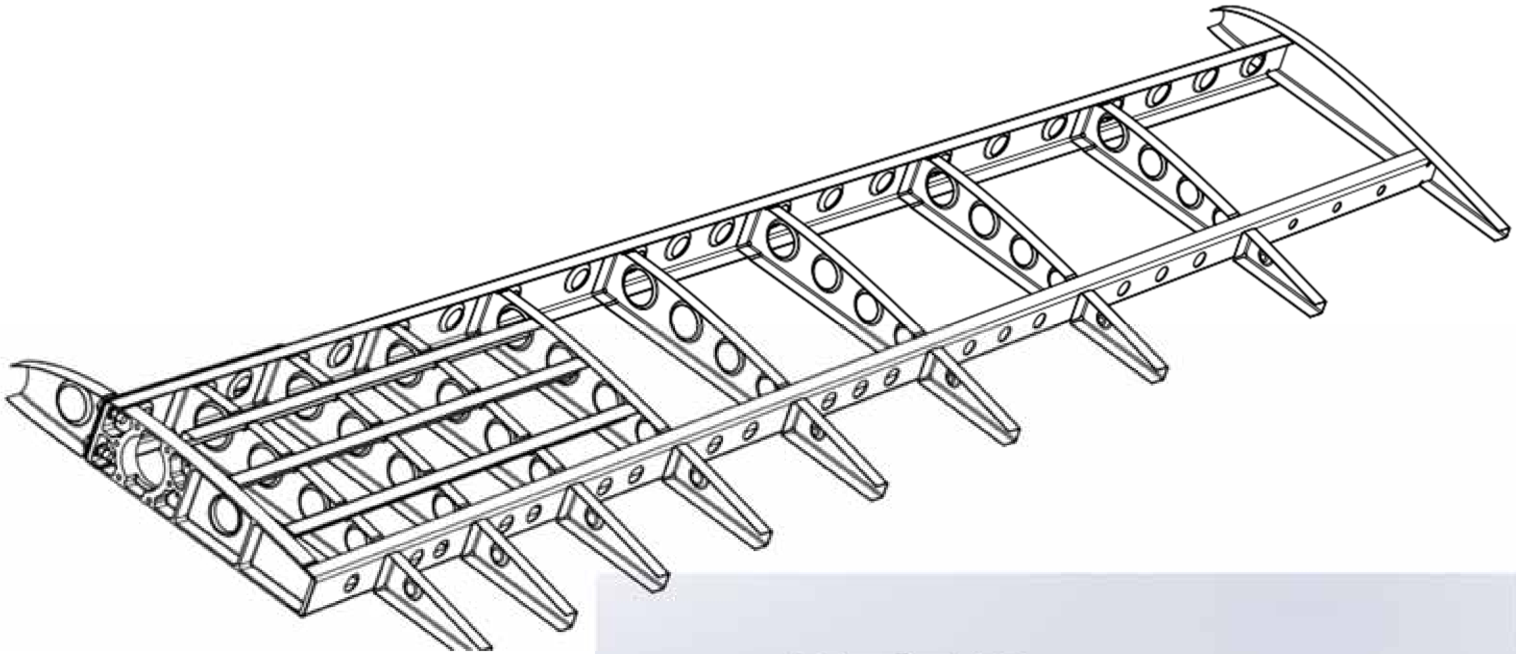
RIBES wing

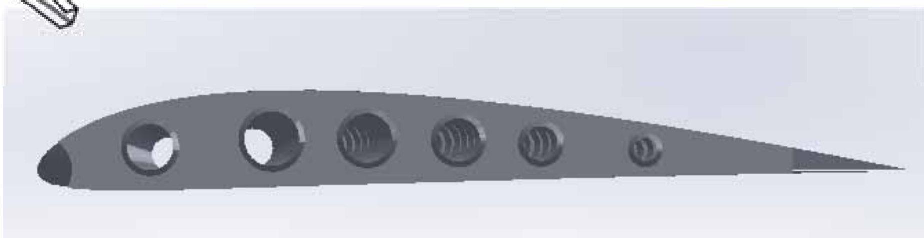


Critical points of design

- Challenging structural similitude with a real full scale wing
  - Impracticable manufacturing
- Conflicting high deformation requirement
  - Relatively higher thickness and lower loads
  - Difficult to load the spars and unload the skin
    - Panels stability was the main design driver
- Manufacturing requirements defined on progress
  - Several iteration with the model manufacturer

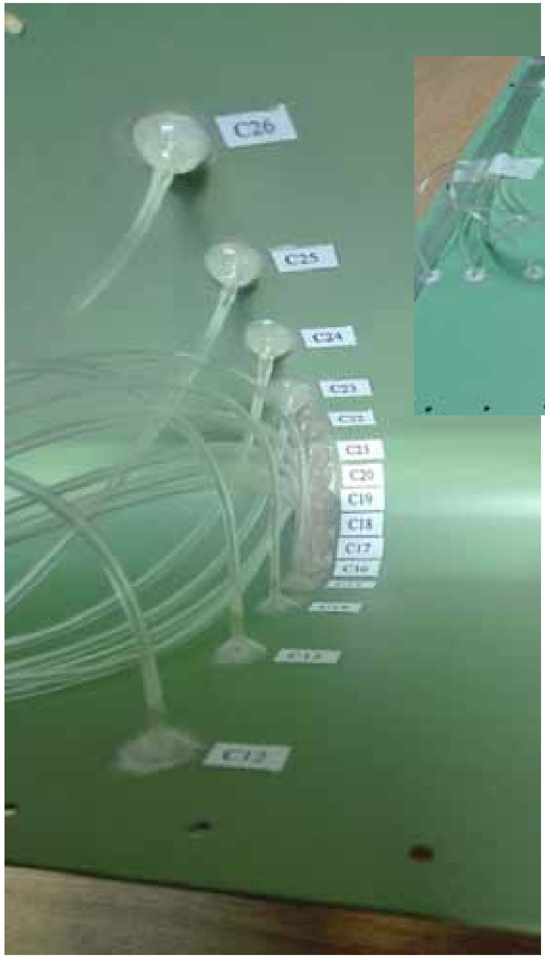
Final test article details

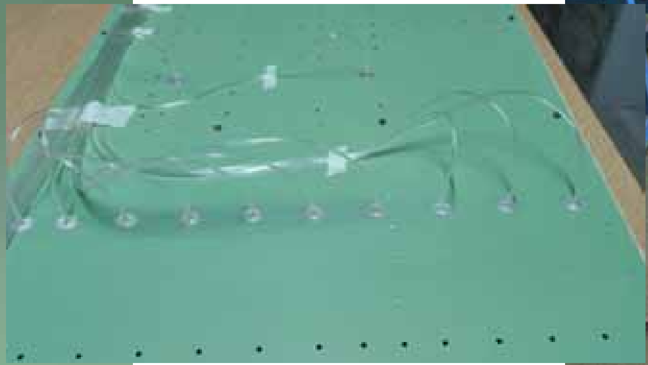


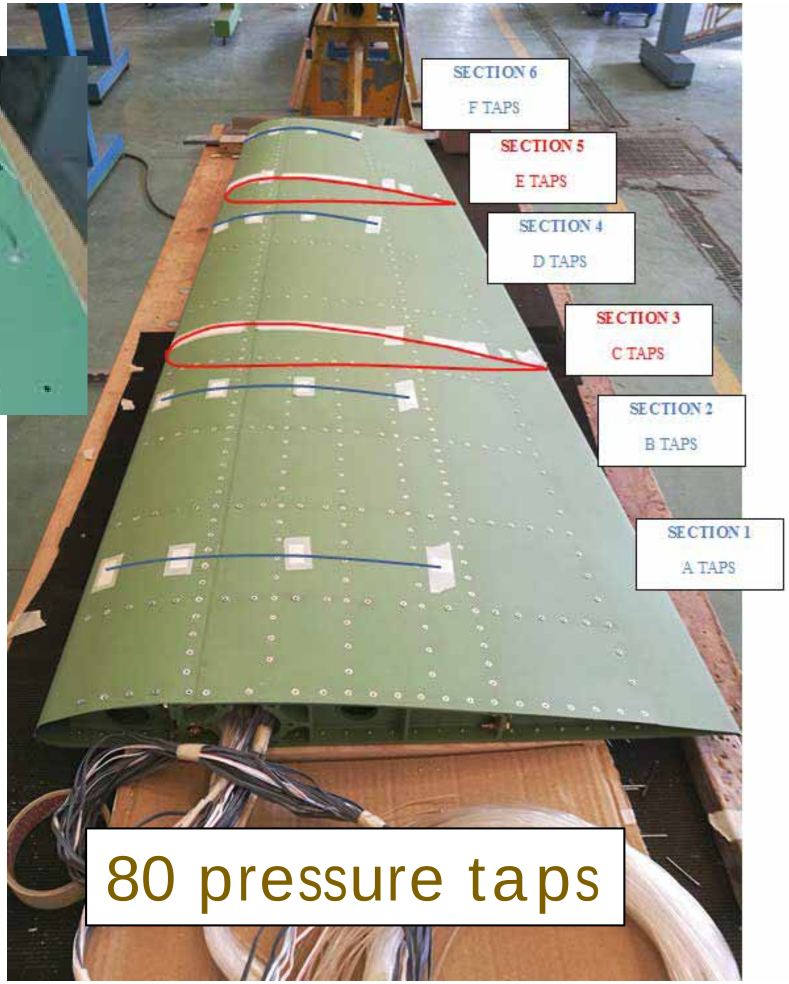


Span = 1.6 m
Material = AL2024T3 (Yeld Stress = 270 Mpa, Ultimate stress = 440 Mpa)

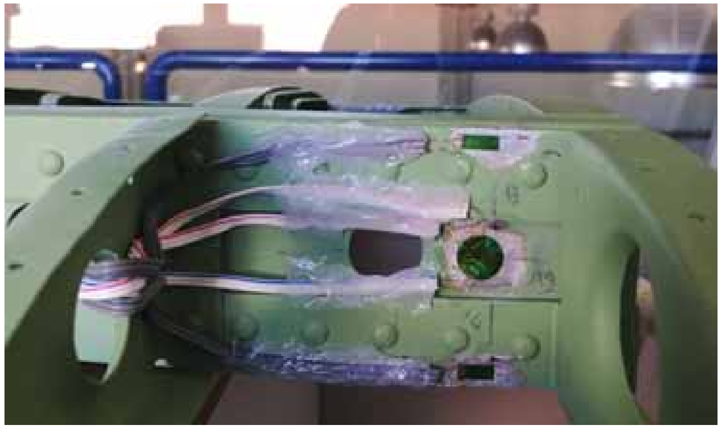
Pressure taps installation



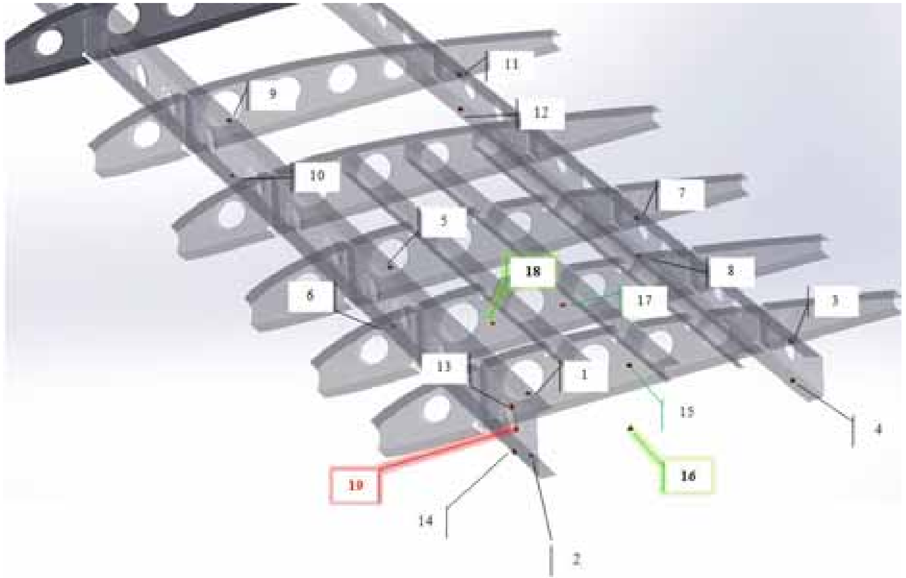




Strain gauges installation



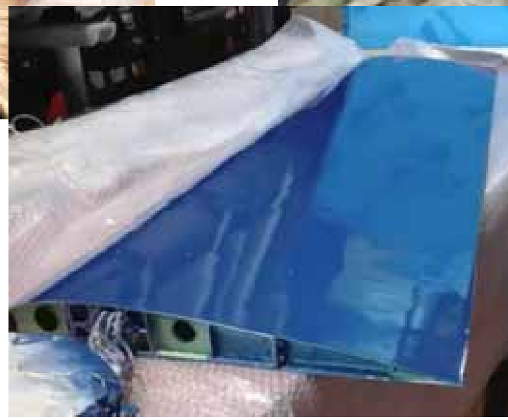
3 rosettes (three channels)
16 unidirectional



Model under construction

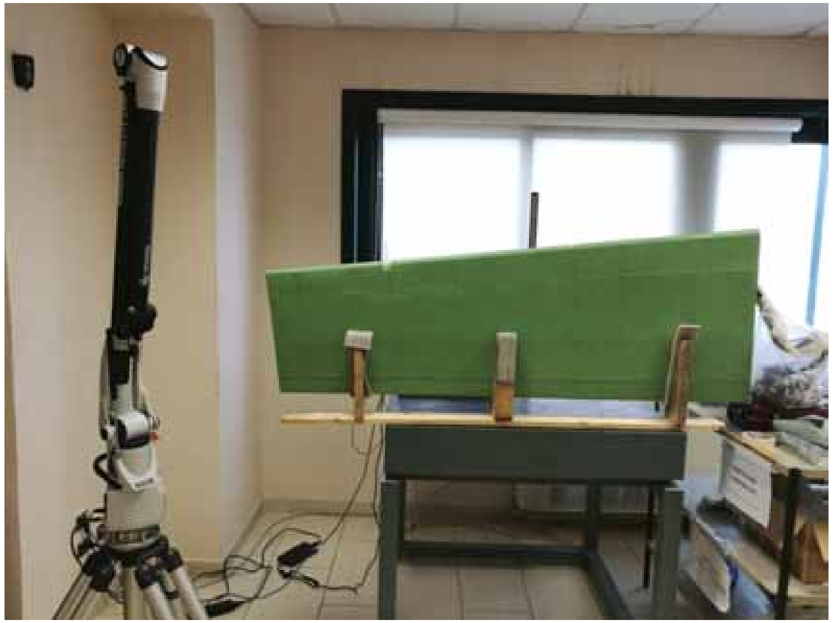




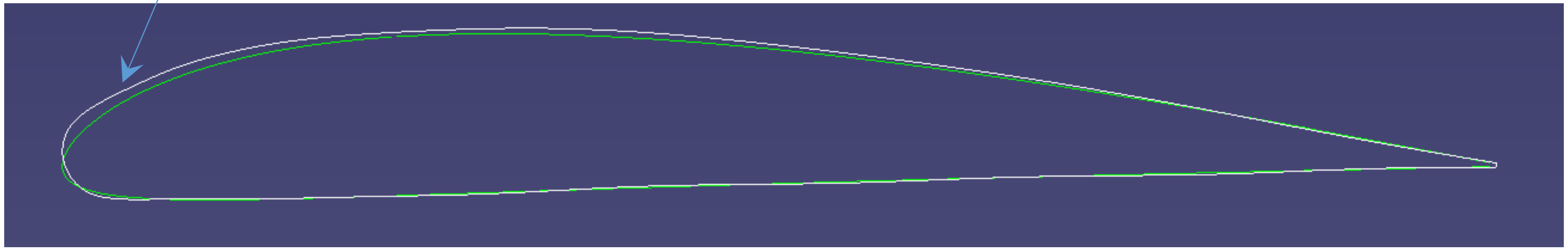


Measured geometry

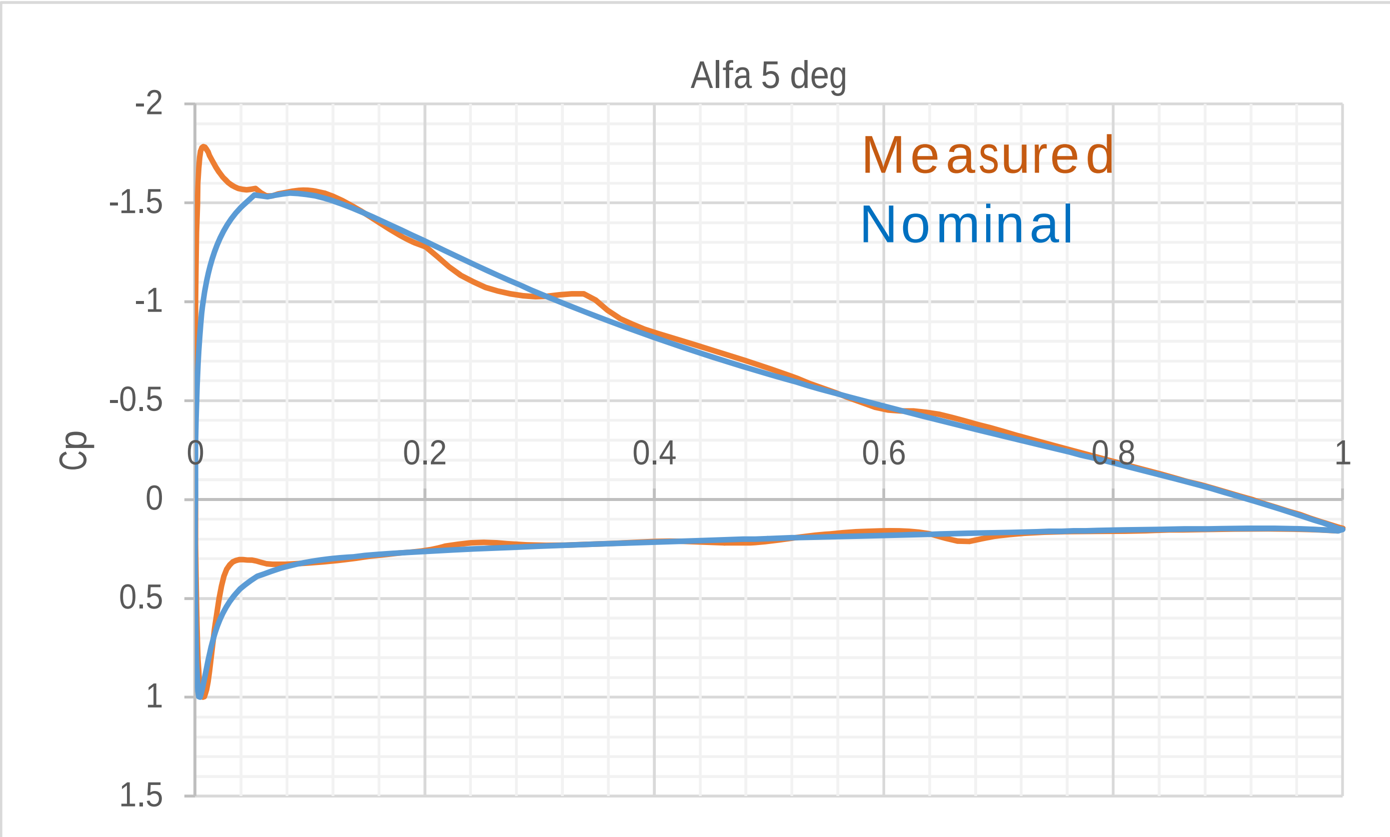
model measured by **HEXAGON metrology electronic harm**



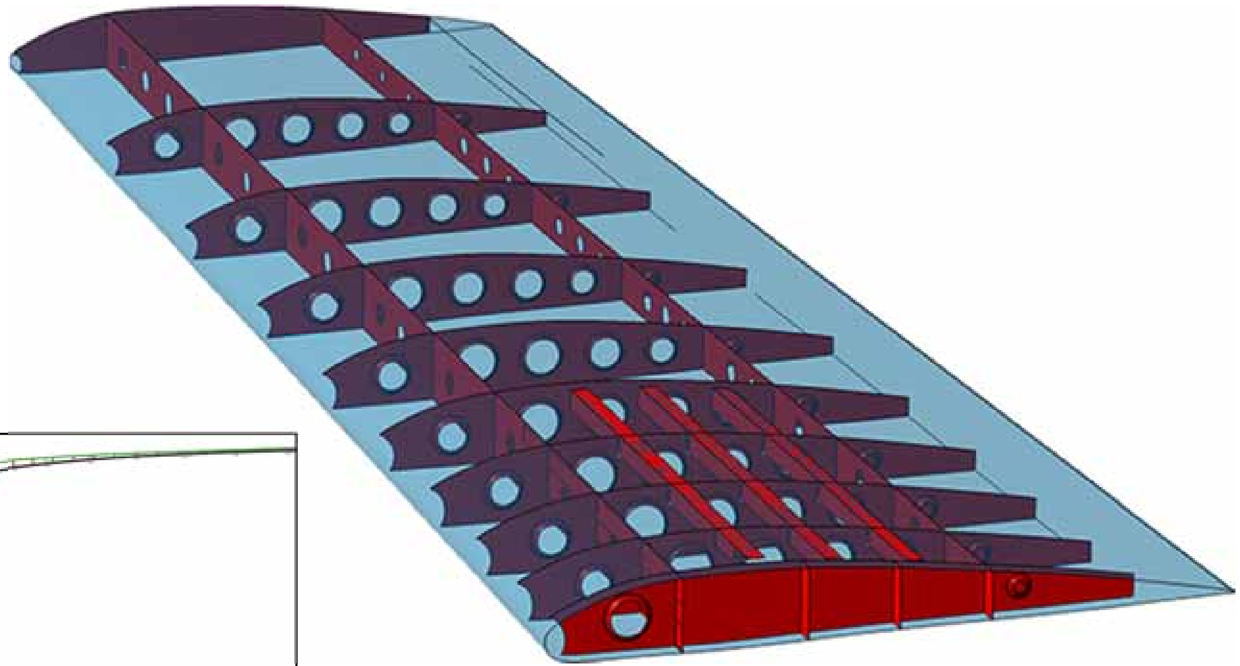
measured

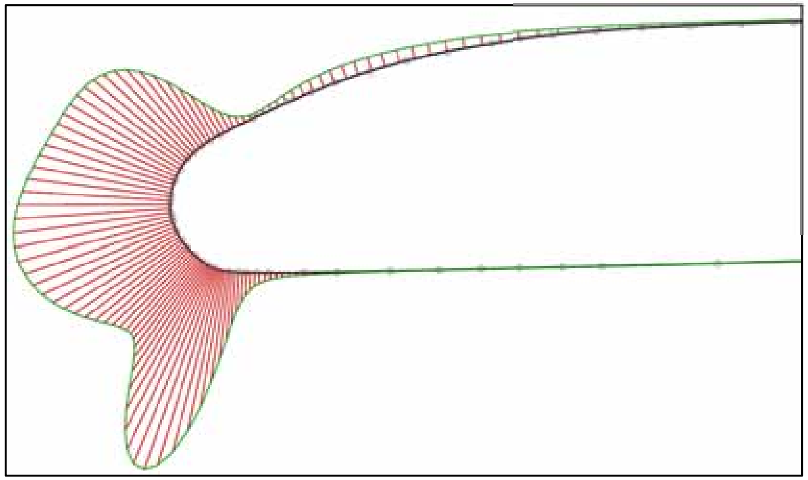


Effects on aerodynamics

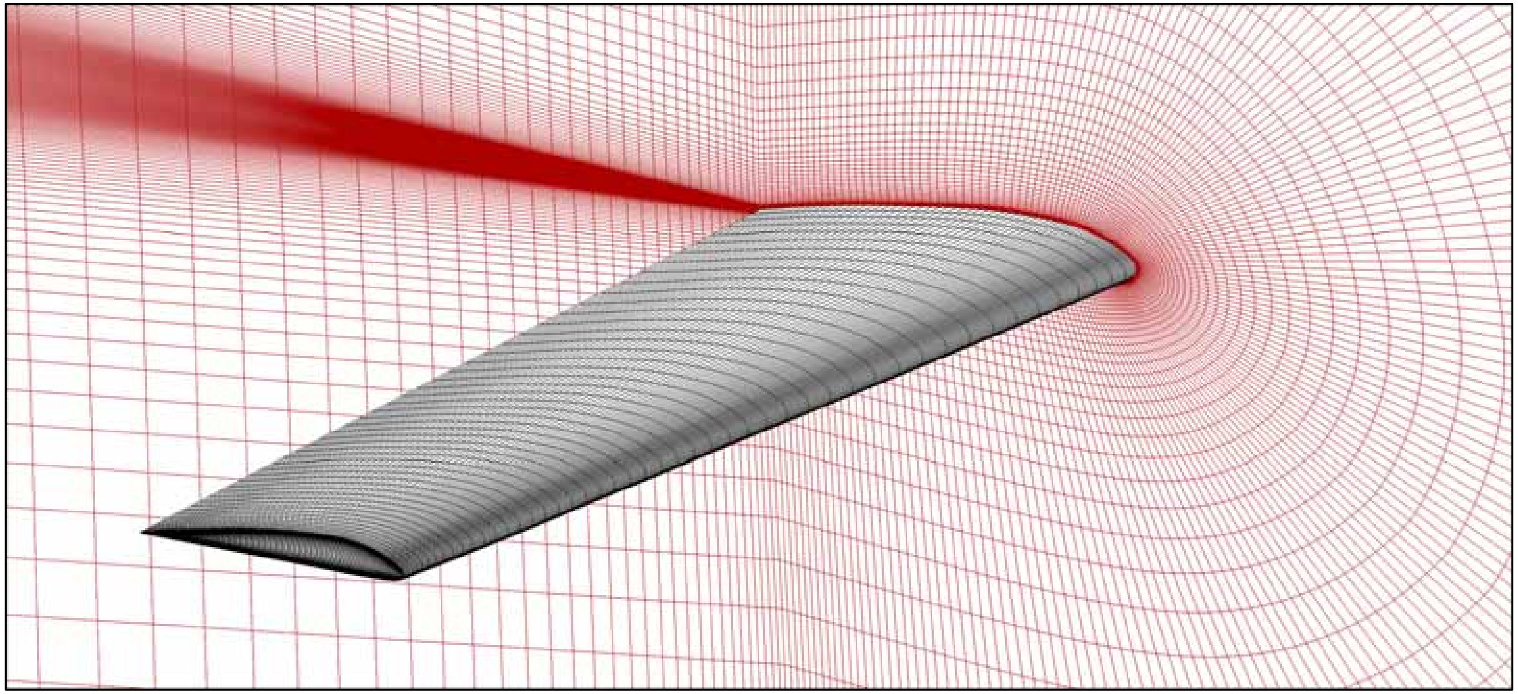


CAD reconstruction



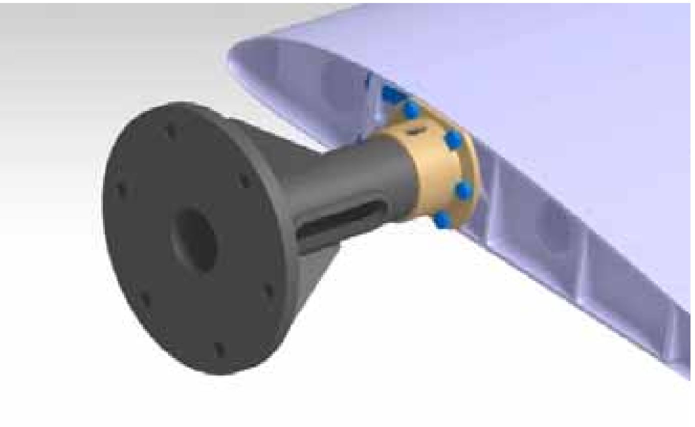


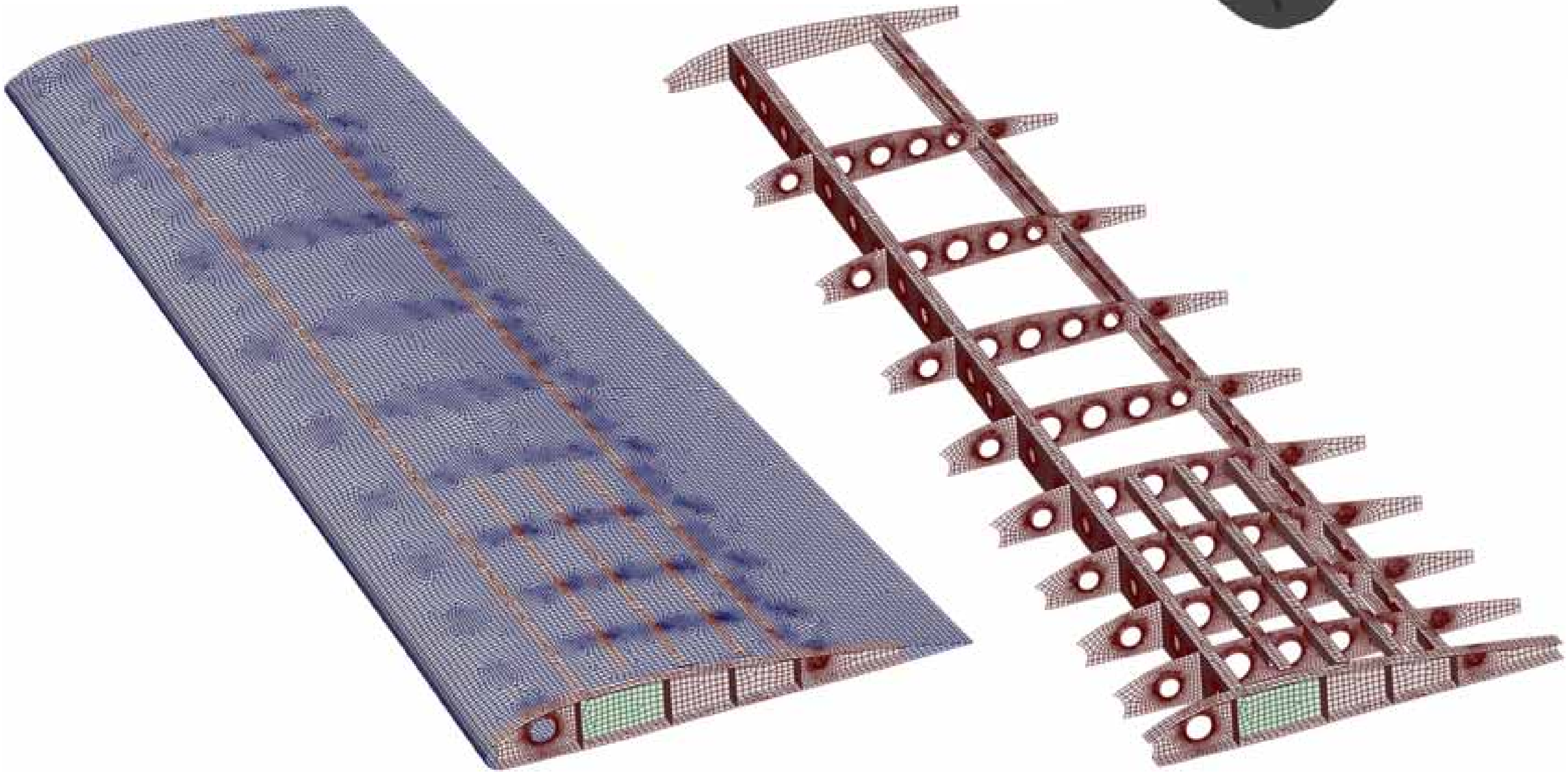
Free flight CFD domain



C-H structured 3.2 mill. Hexa, farfield at 50 MAC

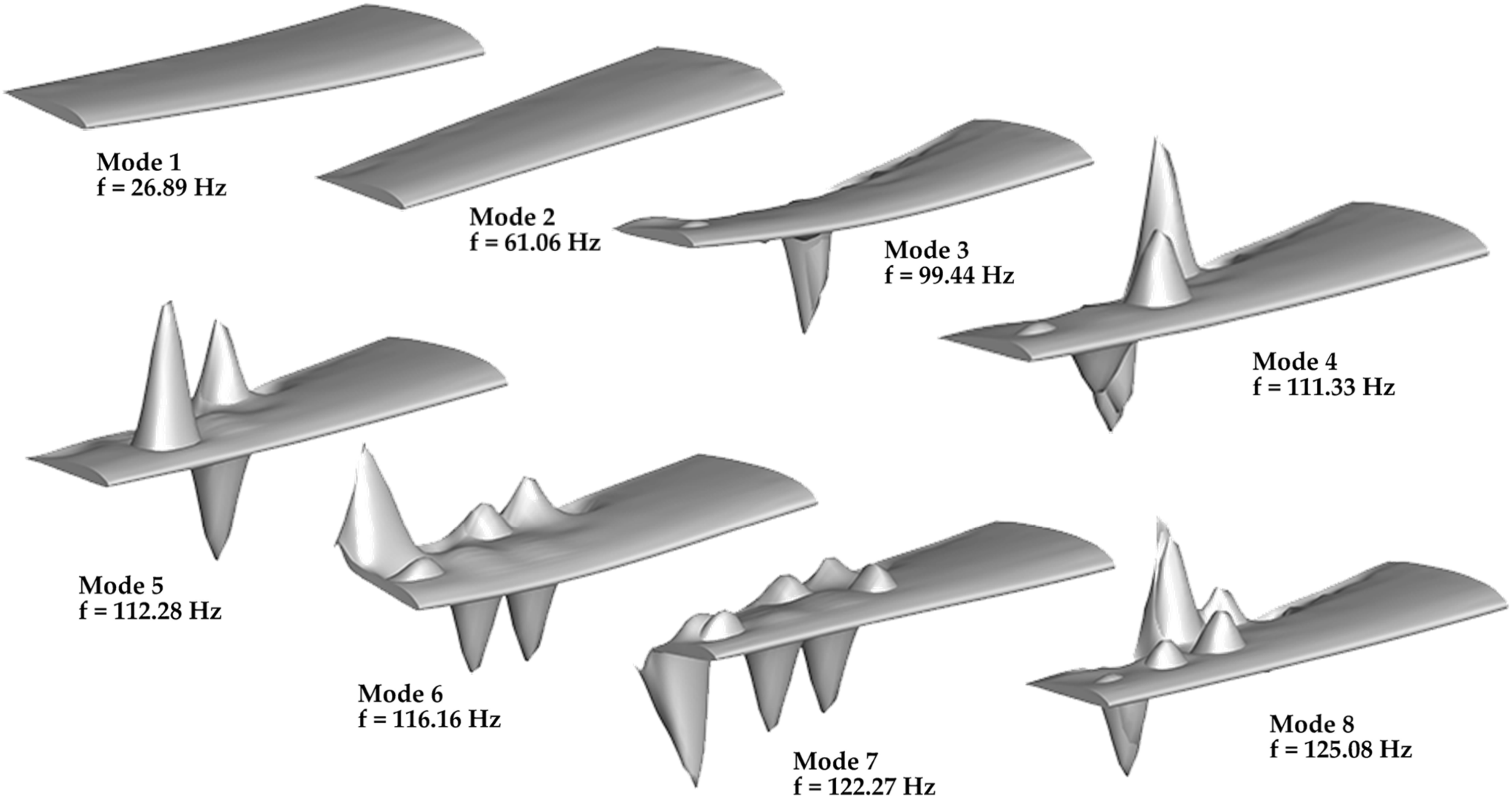
Structural model



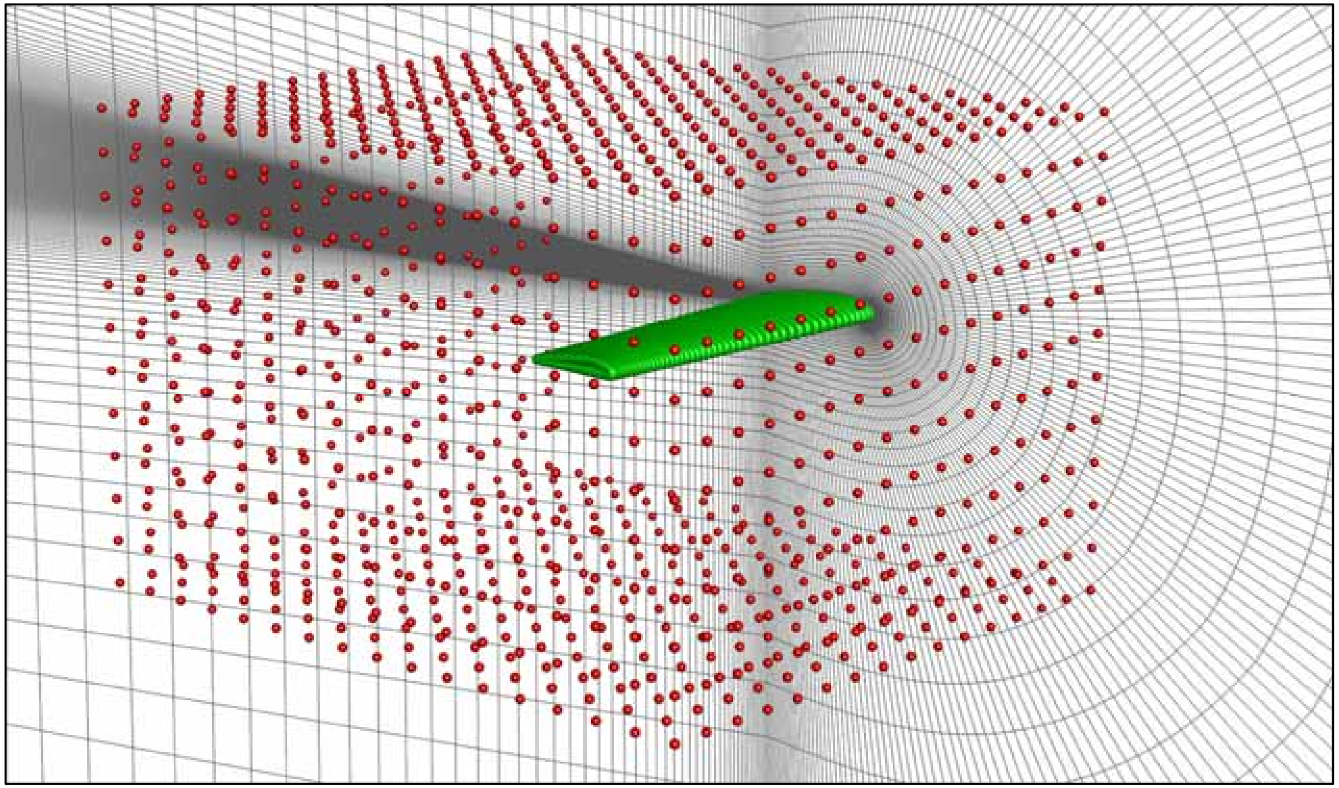


97000 shell elements

Modal shapes

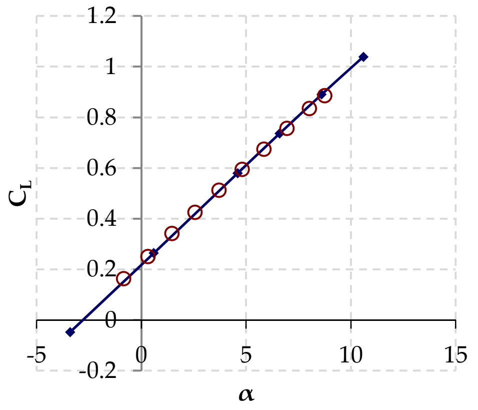


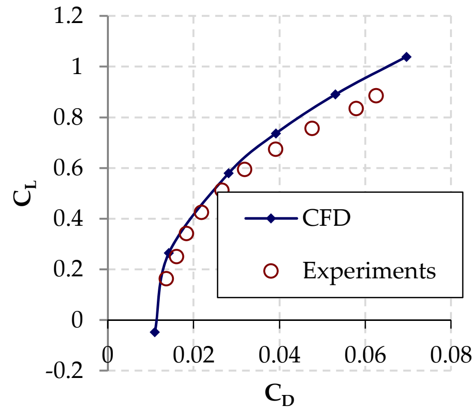
RBF problem domain



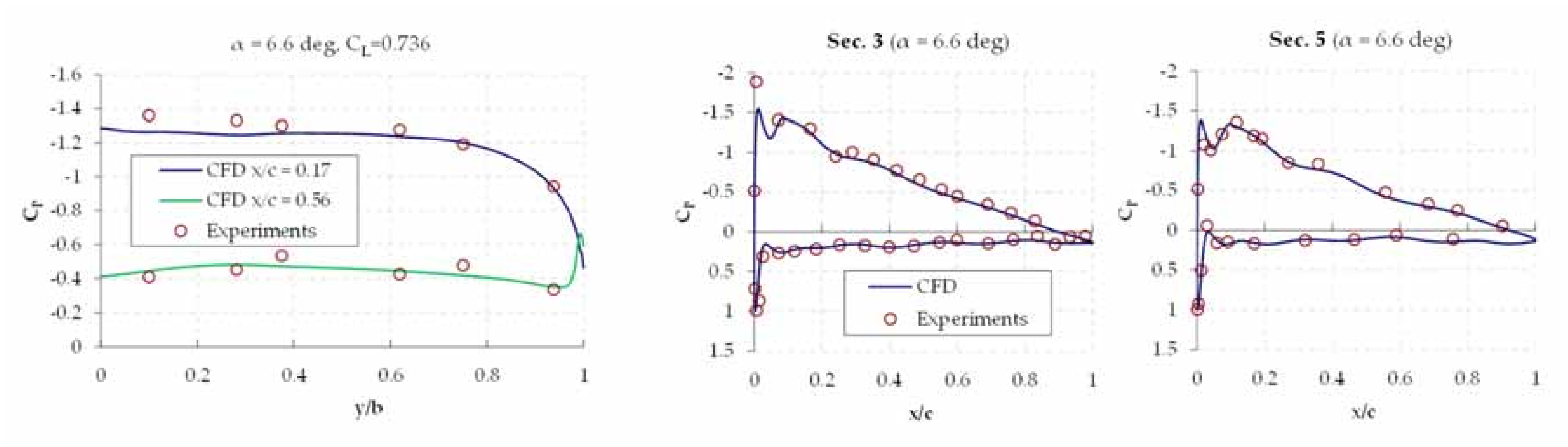
31000 source points, (fitting in 62 sec., smoothing in 40 sec.)

Aerodynamic solutions



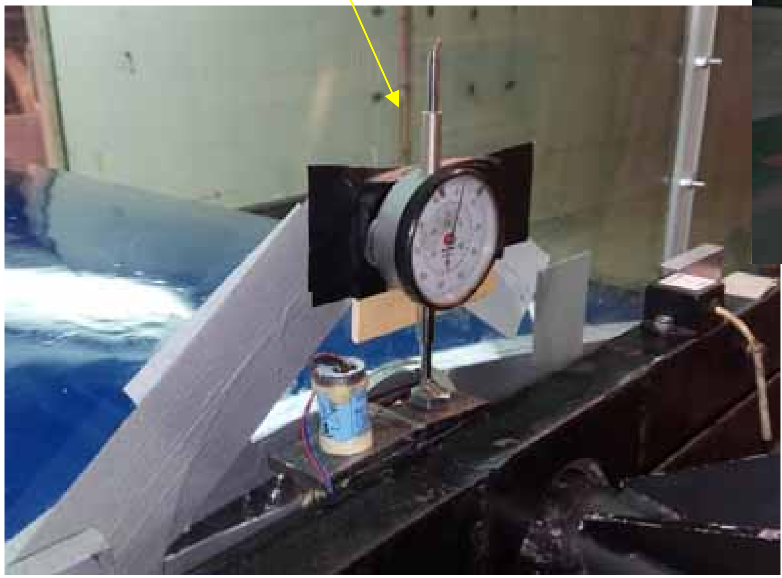


CFD with rigid model (no elasticity accounted)

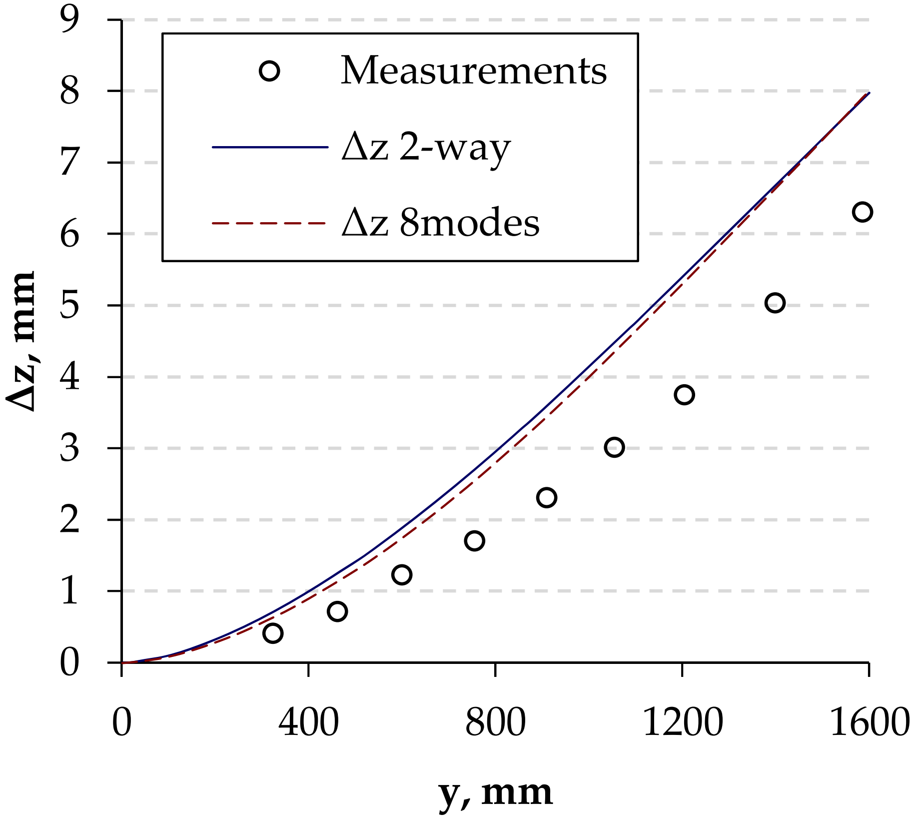


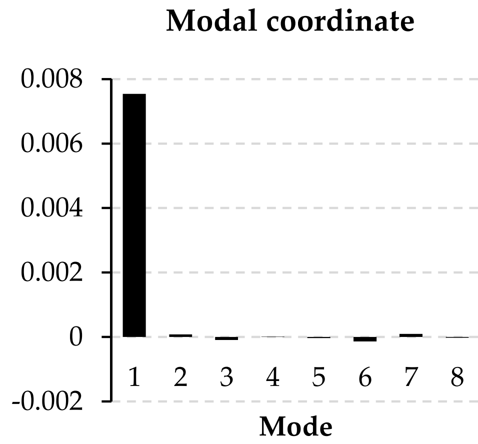
Deformation measurement

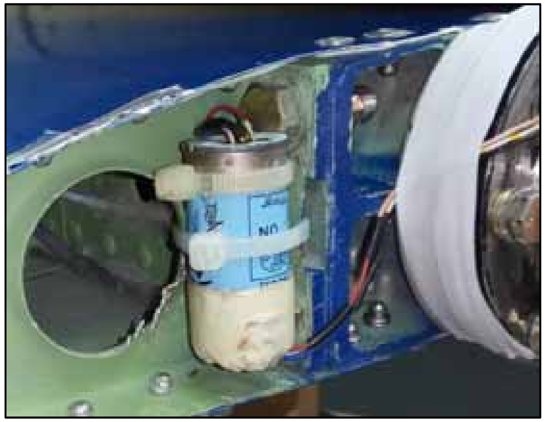
High-precision
inclinometer



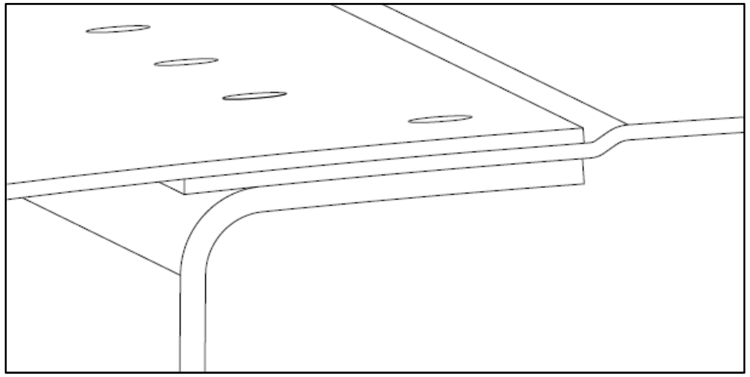
Deformation solutions

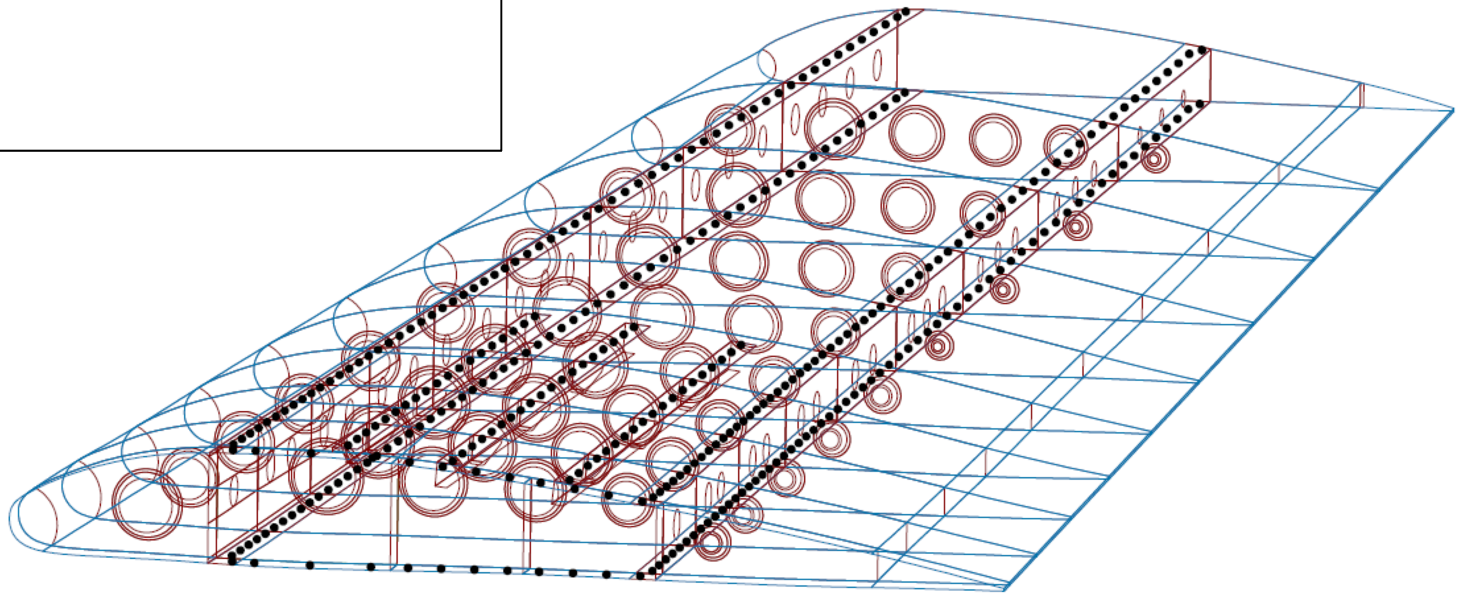






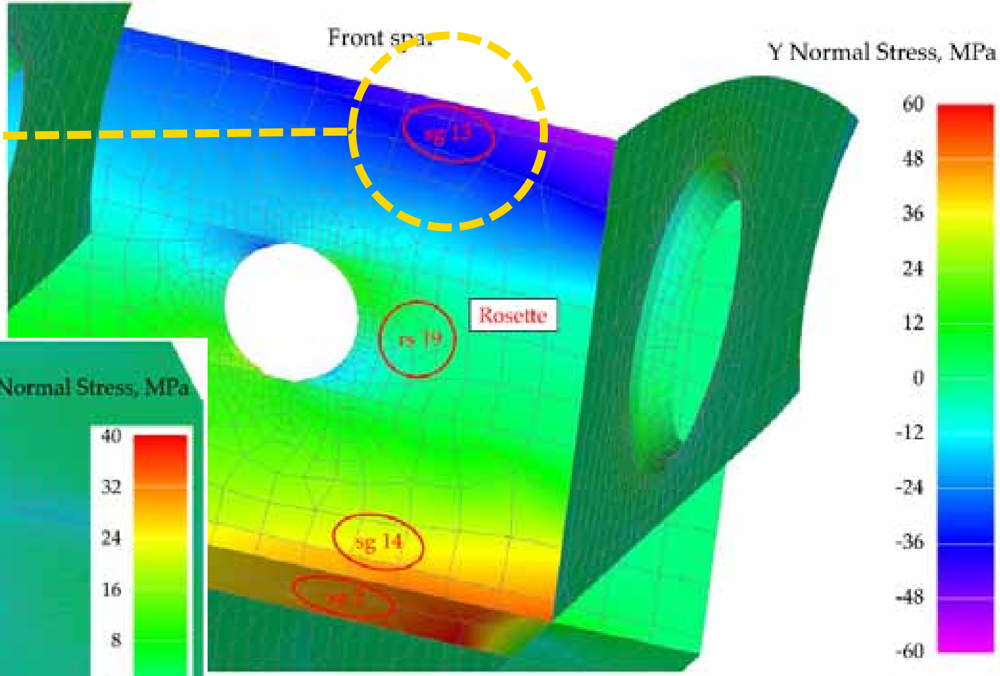
Elements junction

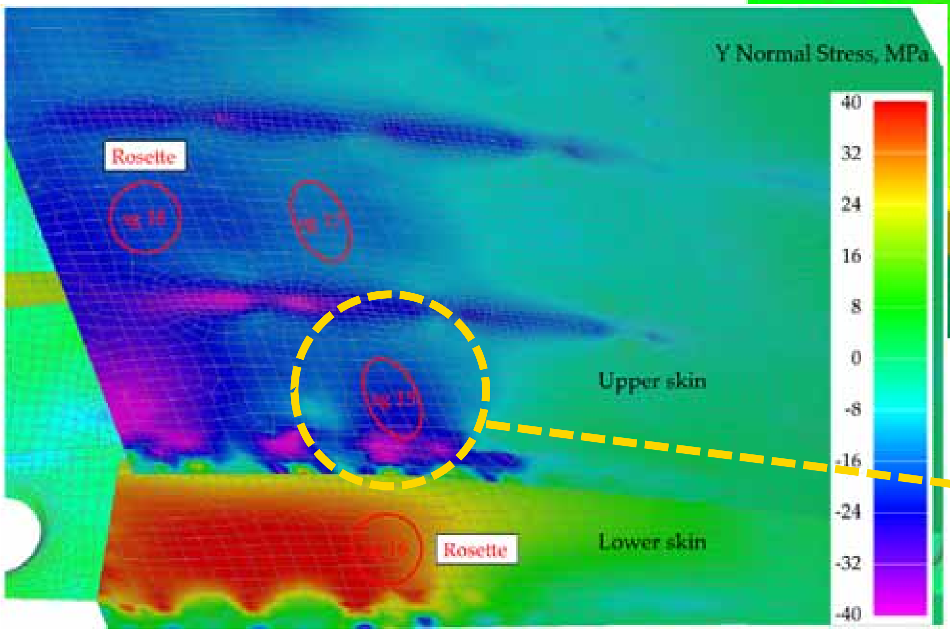




FEM verification

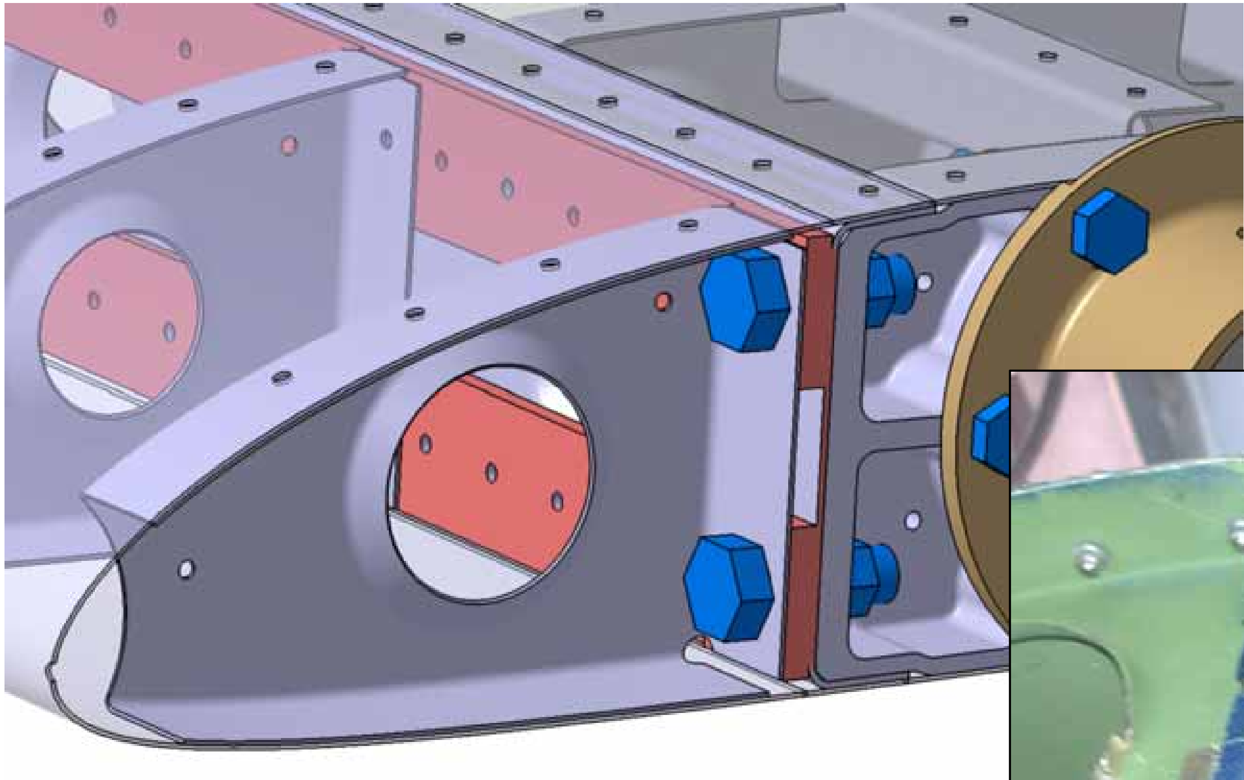
Exp. σ_y = **-15.6** *MPa*
FEM σ_y = ~ **-38** *MPa*





Exp. σ_y = **-143.2** *MPa*
FEM σ_y = ~ **-21** *MPa*

Spar reinforcements

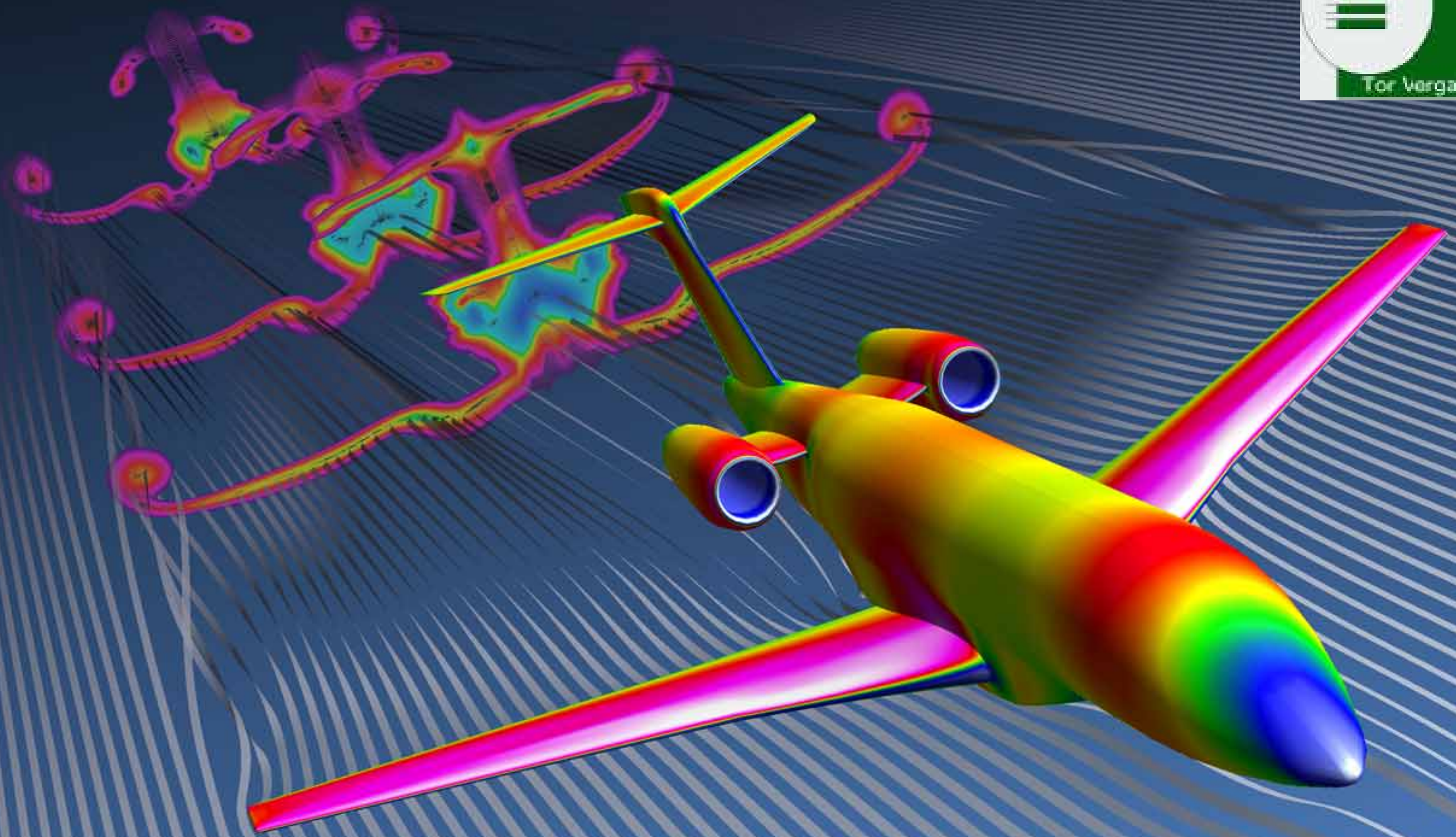


Conclusions

- RBF morphing provide a very efficient and robust coupling of CFD and FEM solutions
- 2-way and modal FSI analyses provided almost the same solutions
  - the modal approach is a valid candidate to setup efficient and accurate FSI analyses of wings
  - A very poorly populated modal base us sufficient for lifting surfaces
- Failure in modeling the load shared between skin and spar.
  - A more accurate FEM model is probably necessary for complex topologies including root junctions

Future work

- Unsteady dynamic FSI implementation to study complex phenomena as flutter or buffet.
- Validation against dynamic test cases
  - HiReNASD ?
  - AGARD 445.6 ?
  - Extension of RIBES model tests?
  - Sails ?



Thank you for your attention

Ubaldo Cella