Towards fully automated aerodynamic shape optimization of nonplanar wings with SU2

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AGENDA

I. **Introduction: need for aerodynamic shape optimization of nonplanar configurations**

II. SU2 and Aerodynamic Shape Optimization

III. SU2 inside MDAO: NERONE

IV. Conclusions and future works

Introduction

Need for aerodynamic shape optimization of nonplanar configurations

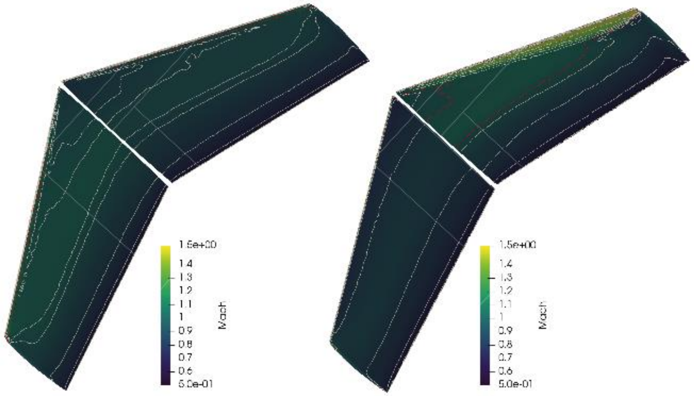
Sustainability

- Environmental challenge and increase in the demand due to the need for mobility.
- More efficient aircraft
    - Design: introduction of higher-fidelity MDO ab-initio
    - Unconventional configurations

Aerodynamic Shape Optimization

- The majority of commercial flights do operate in transonic regimes
    - properly modeling transonic flow physics is costly, and also difficult;
    - enhanced sensitiveness with respect to small and localized features of the **wing shape;**
    - to exploit the potentials of aerodynamic shape optimization (ASO), a **rich-enough design space** has to be considered;
    - adjoint method is the perfect candidate to perform such optimization sensitivities at a relatively low computational costs (cost of evaluating the gradient is almost independent of the number of design variables).

M = 0.8



AoA = 0 deg **AoA = 3.06 deg**

Introduction

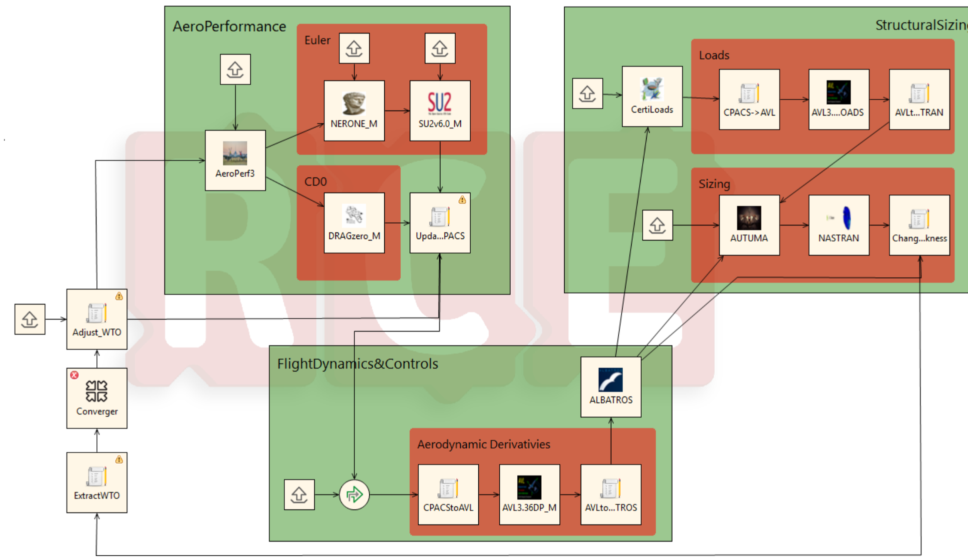
Aerodynamic Shape Optimization inside MDAO

Typically multi-level optimization problems:

- external variation of planform-level DV (sweep, dihedral, etc.
- internal local aerodynamic shape optimization (ASO)

Automatization:

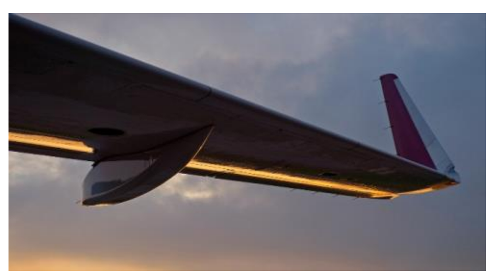
- Parametric description (wing-planform level and local-shape features)
- Robust grid generation (wing-planform level) or deformation (local shape features)
- Aerodynamic Optimization



PARSIFAL
PROJECT

Non-planar wings

- Classic winglets (to reduce drag)
- Box Wings/PrandtlPlane



A320 Sharklet (photo: Airbus)

PrandtlPlane or Box Wing

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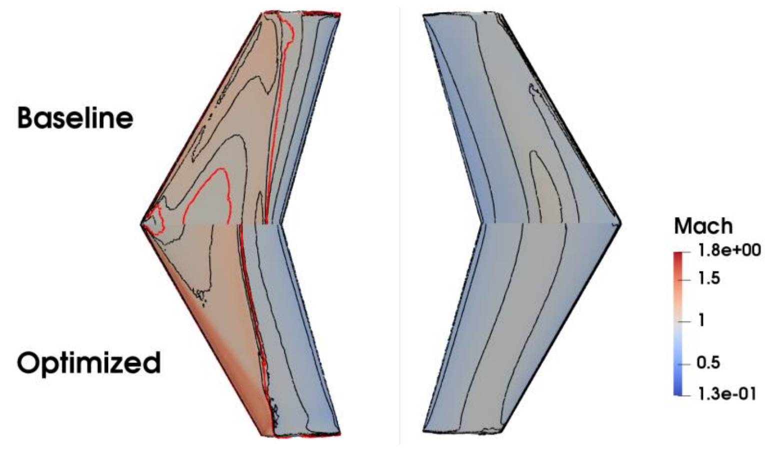
SU2 for Aerodynamic Shape Optimization

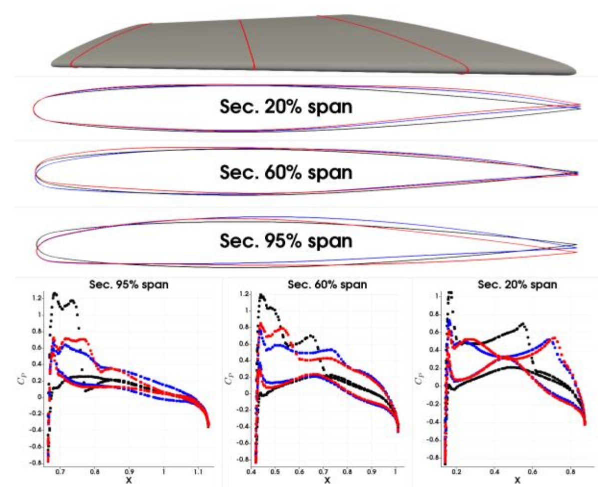
SU2 for Aerodynamic Shape Optimization

- For CFD analyses, continuous and discrete adjoints are provided to support gradient-based optimization.
- Various surface deformation parametrizations and mesh deformation algorithms available.
- High-level routine (python-written) available for aerodynamic shape optimization.

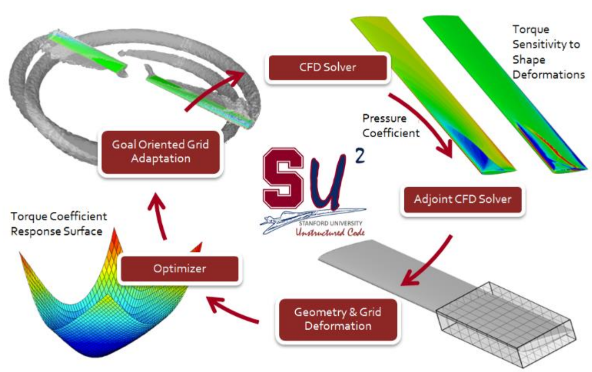
Works well for planar configuration!



Onera M6 testcase

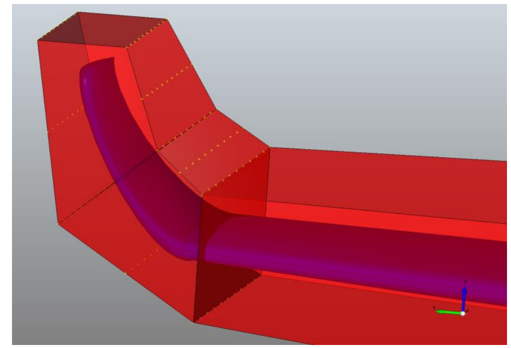


SU2
The Open-Source CFD Code



Issues when considering nonplanar wings:

- Point-inversion not robust.
- Locked position of control points on adjacent FFD boxes.

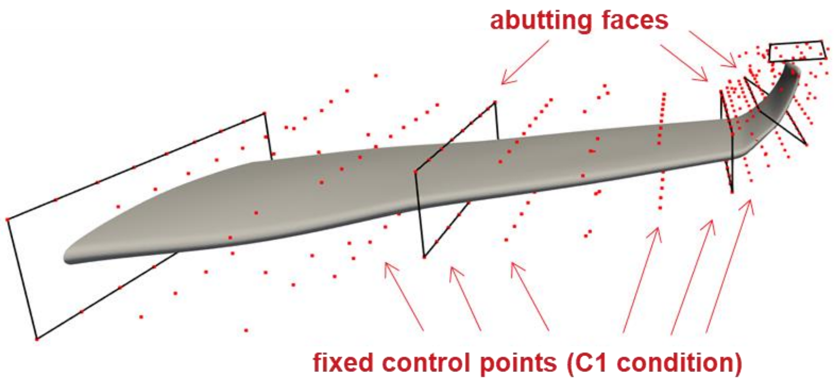


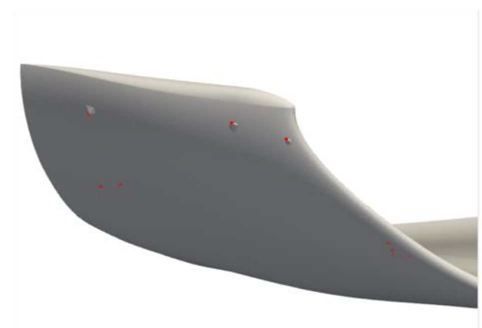
$$\boldsymbol{P} = \sum_{i=0}^{l}\sum_{j=0}^{m}\sum_{k=0}^{n} N_i(\mu)N_j(\chi)N_k(\xi)\boldsymbol{P}_{ijk}$$

surface points

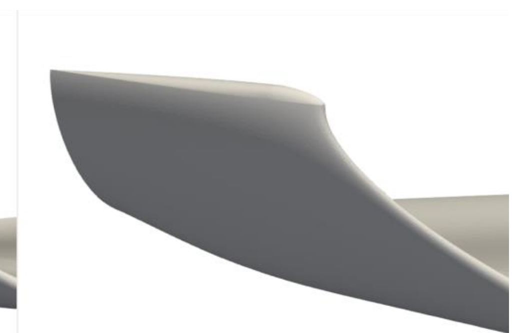
basis functions

Control Points (FFD boxes)





SU2 original code (failed point-inversion)



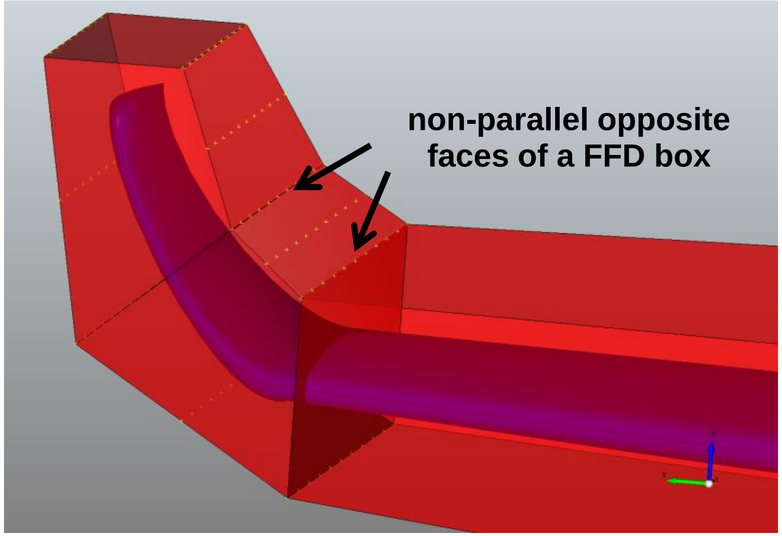
modified SU2 point-inversion

SU2 for Aerodynamic Shape Optimization

Functionalities added to SU2 core

Robust point-inversion to allow non-parallel opposite faces of a FFD box.

- use of genetic algorithm for point-inversion (avoids local minima)



$$\boldsymbol{P} = \sum_{i=0}^{l} \sum_{j=0}^{m} \sum_{k=0}^{n} N_i(\mu) N_j(\chi) N_k(\xi) \boldsymbol{P}_{ijk}$$

surface points

basis functions

Control Points (FFD boxes)

Changes in "*grid_movement_structure.cpp*" file, "*CsurfaceMovement::SetParametricCoord*" class member function

- if the SU2 original point inversion algorithm fails (parametric coordinates not bounded in [0,1]) a new genetic algorithm (based on https://www.iitk.ac.in/kangal/codes.shtml) is called

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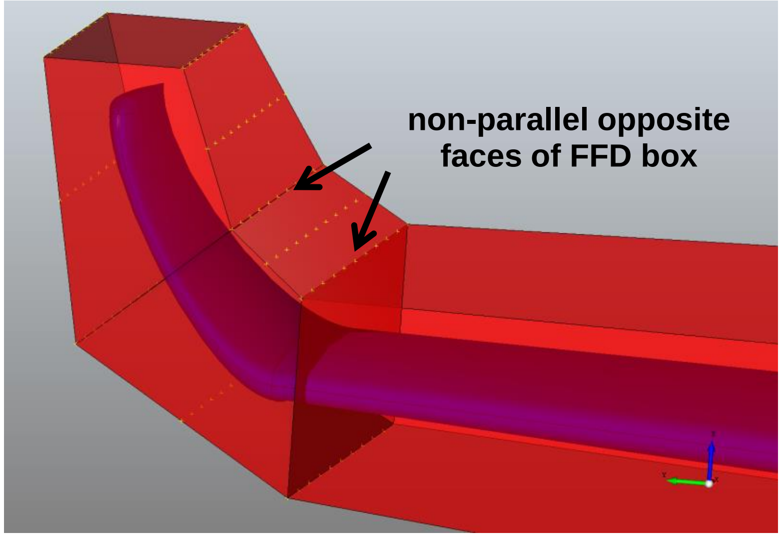
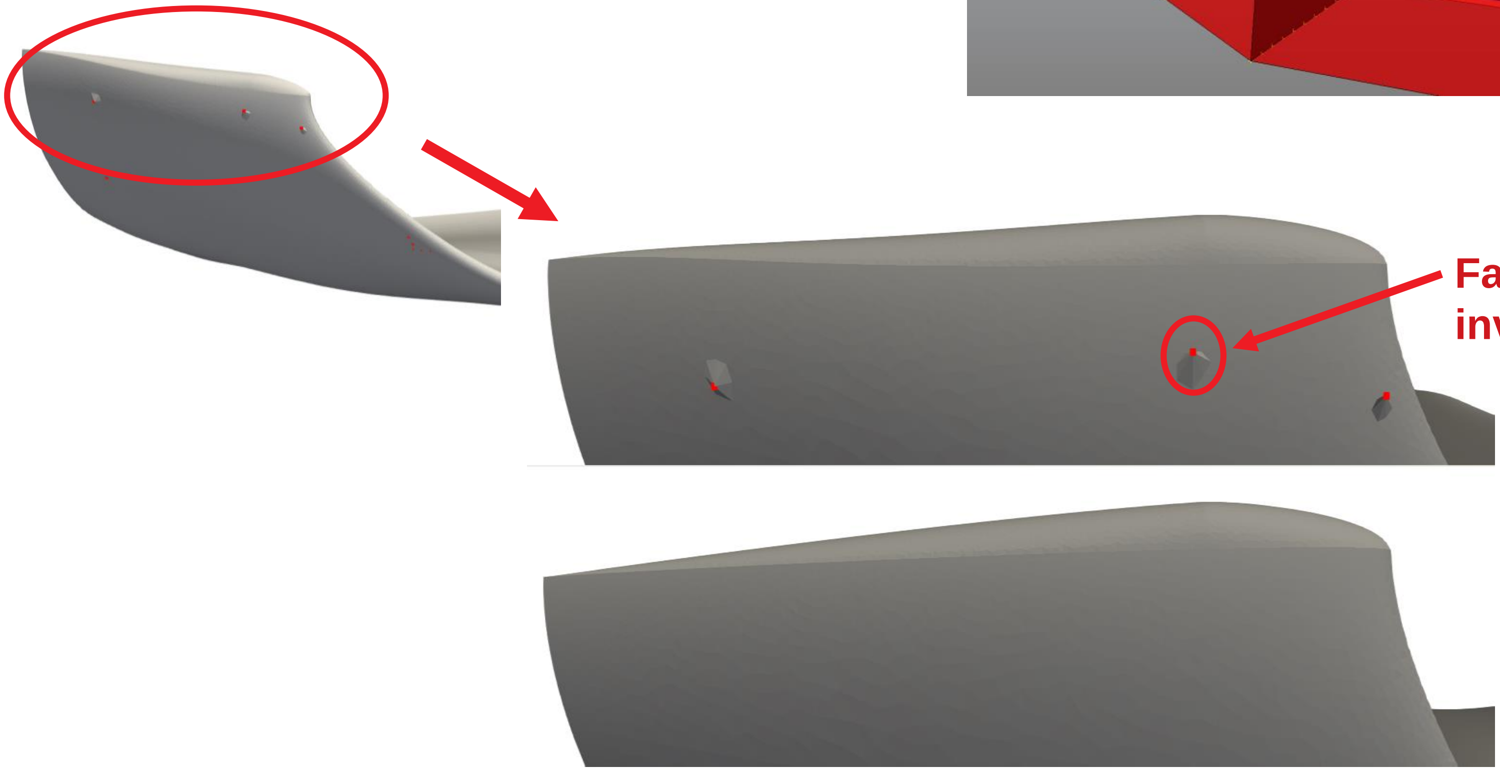




Failed point-inversion

SU2 original code, random deformation.

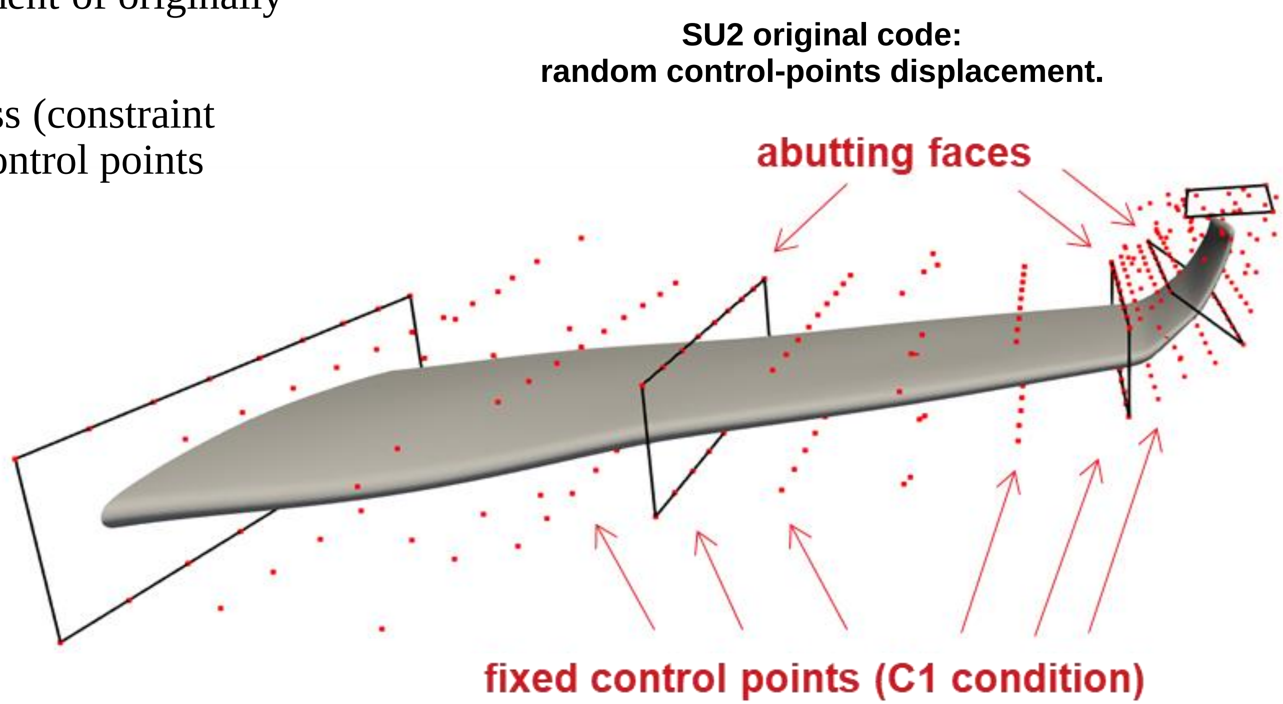
modified SU2, random deformation.

SU2 for Aerodynamic Shape Optimization

Functionalities added to SU2 core

New conditions on adjacent FFD boxes control points:

- Allows for displacement of originally fixed control points.
- Maintains smoothness (constraint equations between control points displacements).



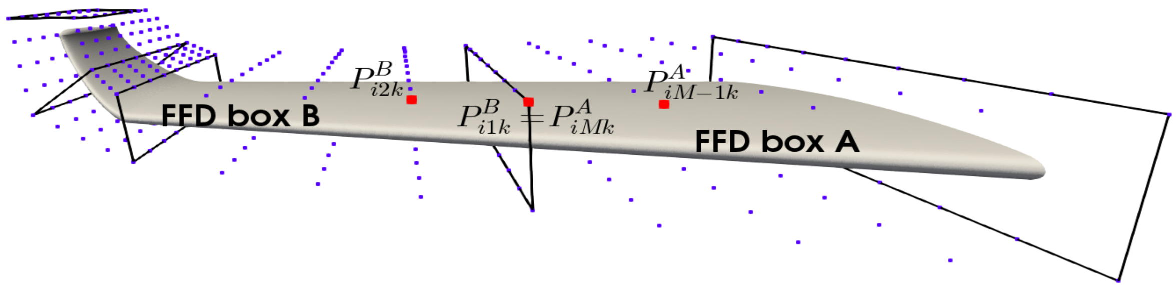
Have been modified:

- python SU2-optimizer interface "*scipy_tools.py*"
- input file and parser "*config.py*"

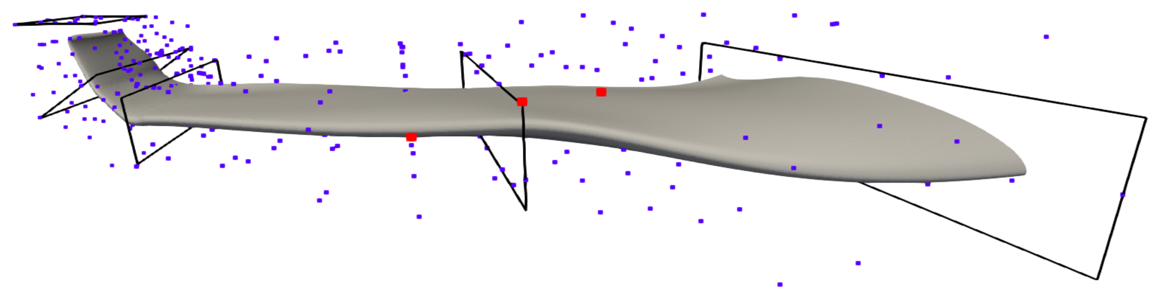
SU2 for Aerodynamic Shape Optimization

Functionalities added to SU2 core

New conditions on adjacent FFD boxes control points.



SU2 modified code: random control-points displacement.



- Continuity requirements on control points up- down-stream the shared FFD interfaces to guarantee a certain level of smoothness

$$\delta \boldsymbol{P}^B_{i1k} = \delta \boldsymbol{P}^A_{iMk} = \frac{\delta \boldsymbol{P}^A_{iM-1k} + \delta \boldsymbol{P}^B_{i2k}}{2}$$

- Dependent design variables (control points) eliminated from the independent DVs.

$$J = J(\delta \boldsymbol{P}^A_{ijk},\ \delta \boldsymbol{P}^B_{rst},\ \delta \boldsymbol{P}^A_{iMk}(\delta \boldsymbol{P}^A_{iM-1k},\ \delta \boldsymbol{P}^B_{i2k}),\ \delta \boldsymbol{P}^B_{i1k}(\delta \boldsymbol{P}^A_{iM-1k}, \delta \boldsymbol{P}^B_{i2k})\ )$$

- Gradient projection adapted to reflect the constraint.

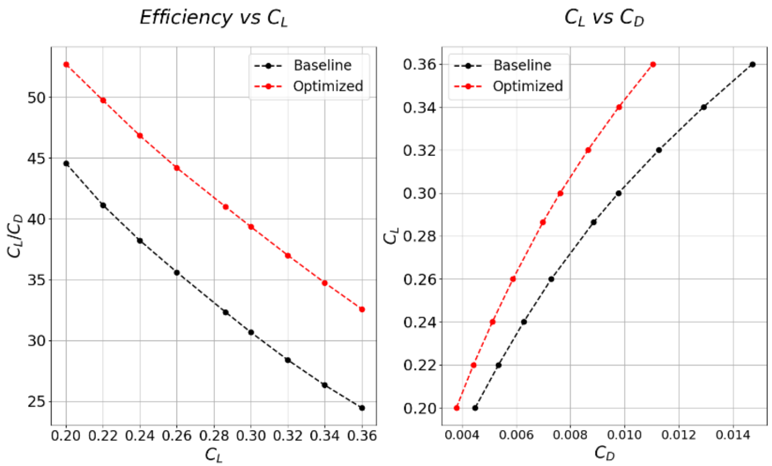
$$\frac{dJ}{d\delta \boldsymbol{P}^A_{iM-1k}} = \frac{\partial J}{\partial \delta \boldsymbol{P}^A_{iM-1k}} + \frac{\partial J}{\partial \delta \boldsymbol{P}^A_{iMk}} \frac{\partial \delta \boldsymbol{P}^A_{iMk}}{\partial \delta \boldsymbol{P}^A_{iM-1k}} + \frac{\partial J}{\partial \delta \boldsymbol{P}^B_{i1k}} \frac{\partial \delta \boldsymbol{P}^B_{i1k}}{\partial \delta \boldsymbol{P}^A_{iM-1k}}$$

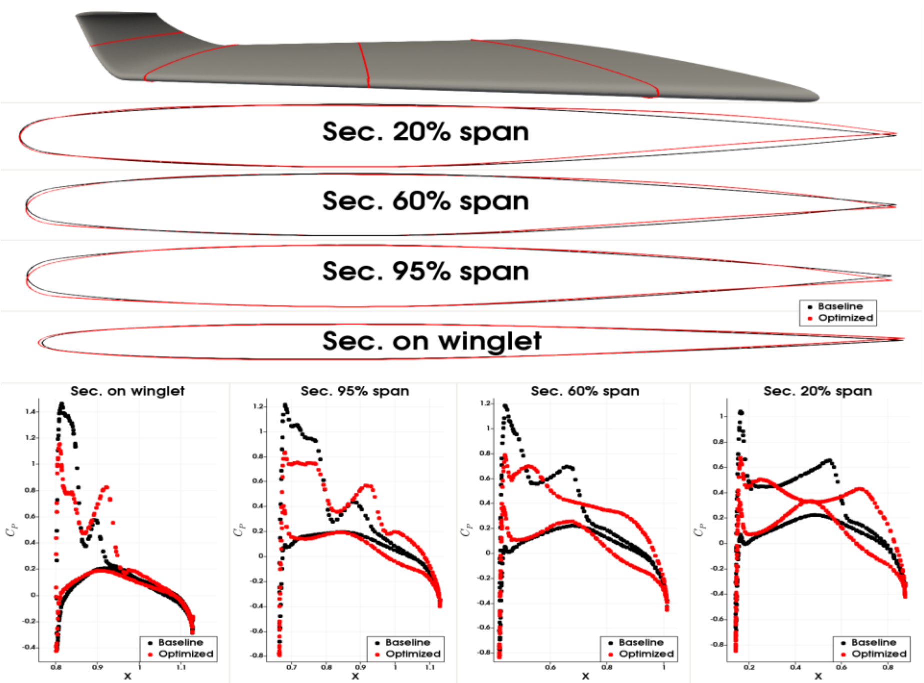
SU2 for Aerodynamic Shape Optimization

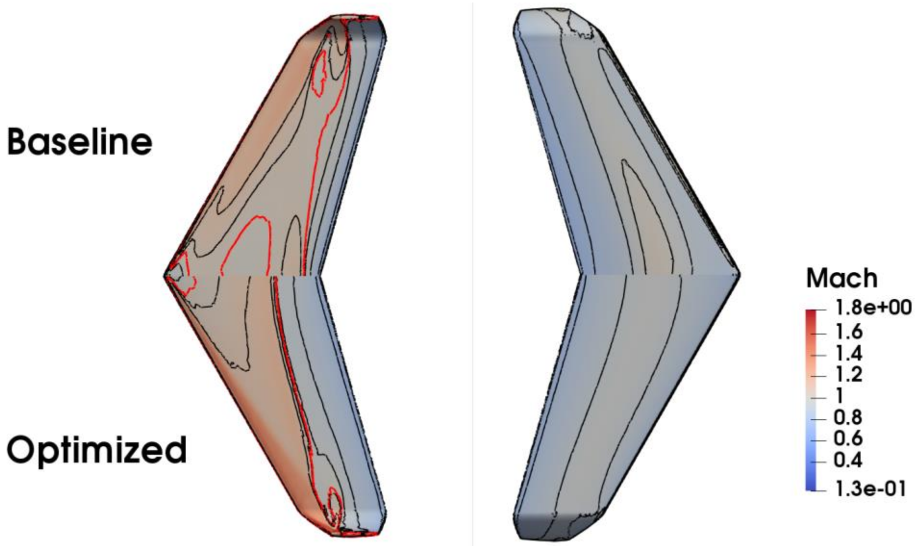
Performance of modified SU2

Synthetic testcase, based on ONERA M6 with added winglets:

- Euler-based
  - multi-point optimization (several C_L, fixed M=0.84) ;
  - t/c and C_M (pitching moment) constraints.







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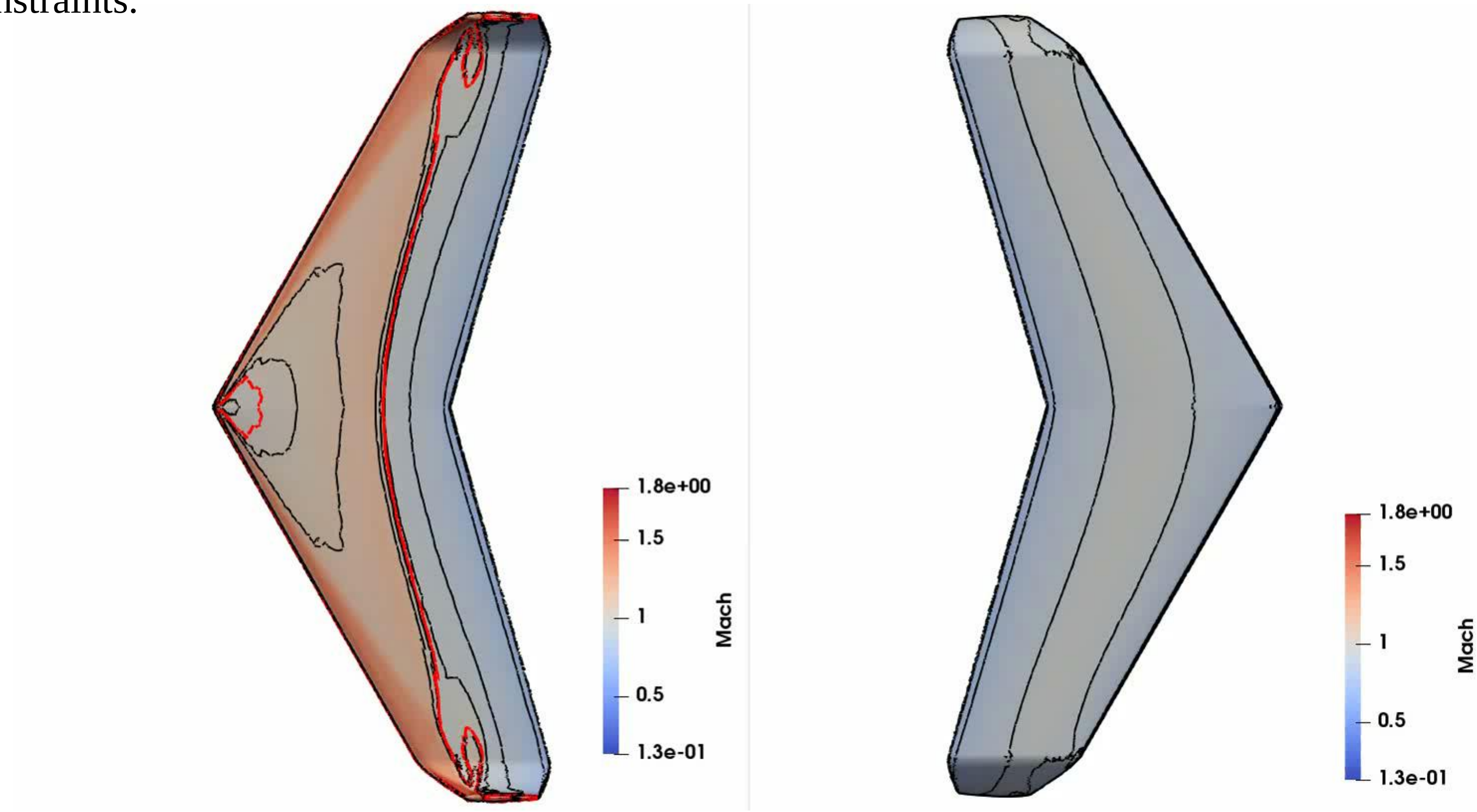

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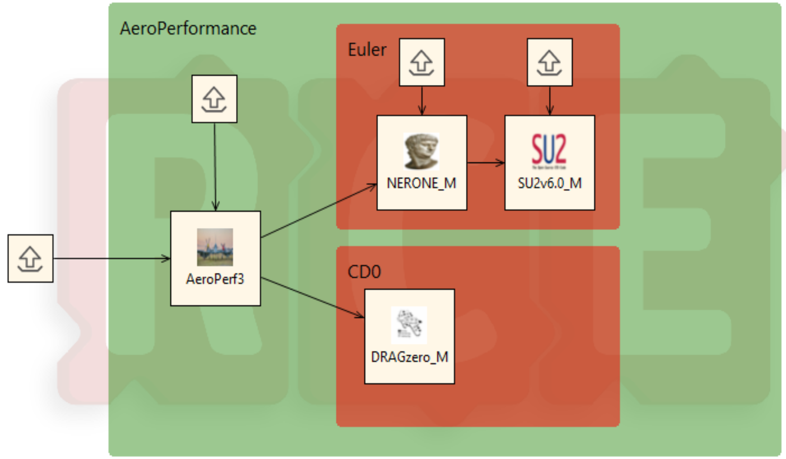
Aerodynamic Shape Optimization: NERONE

NERONE

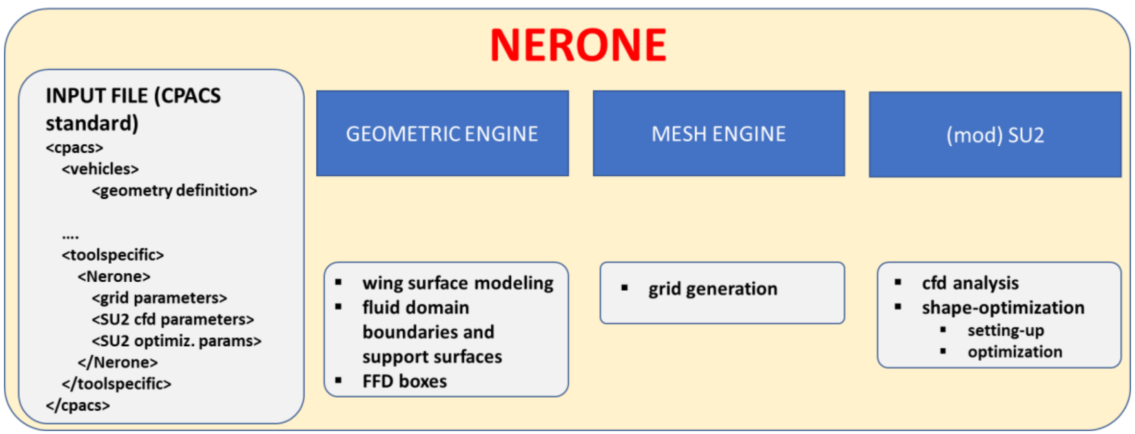
(opeNsource mEsh cReation fOr aerodyNamic Evaluation)

Tool for the aerodynamic shape optimization of **nonplanar** configurations based on open-source software.



Highlights

- Fully automatic.
- Fairing surfaces controlled in an intuitive and robust way.
- User-guided meshing strategy.
- Well-suited to be used within an MDAO workflow.
- *Features added to **SU2** code to handle nonplanar configurations.*

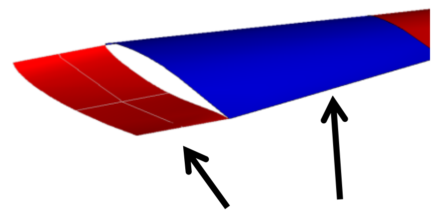


NERONE: Geometric Engine

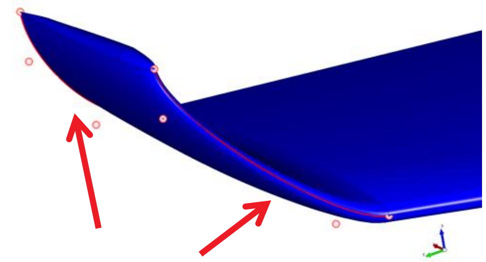
Geometric engine

Based on the **OpenCascade** library.

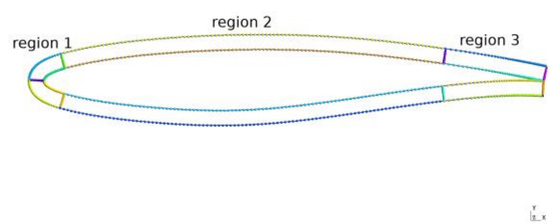
- Converts the **CPACS** (common language) parametric description into a mathematical continuous surface.
- Creates regions on the surface to guide the meshing process.
- Creates external boundaries of the domain, and intermediate surfaces to support meshing process.
- Creates, in case an optimization is carried out, the Free Form Deformation (FFD) boxes.

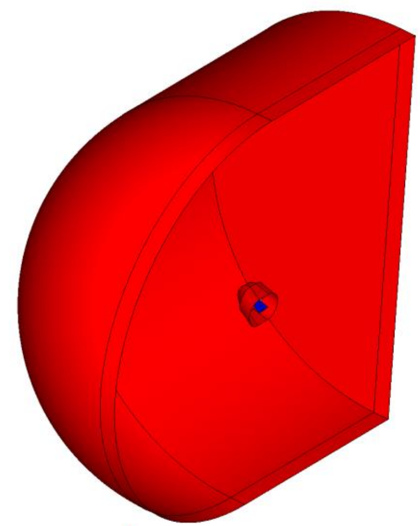


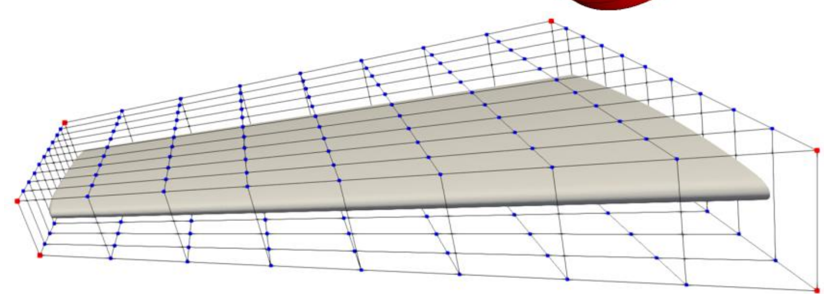
Coons' surfaces



Bezier support curves

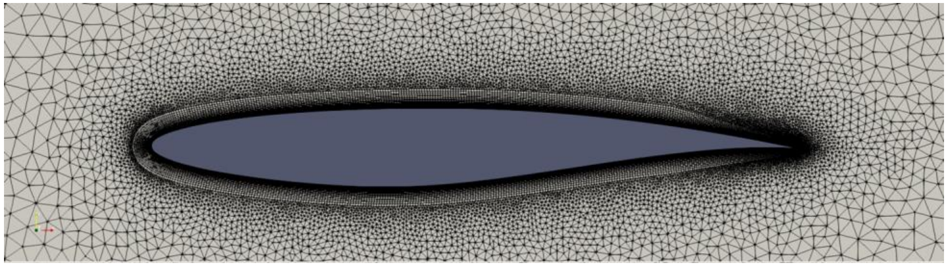






Freeform-deformation (FFD) boxes

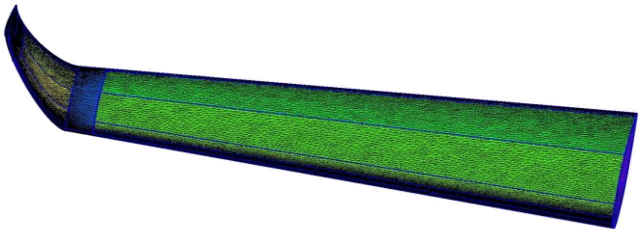
NERONE: Grid Generation module

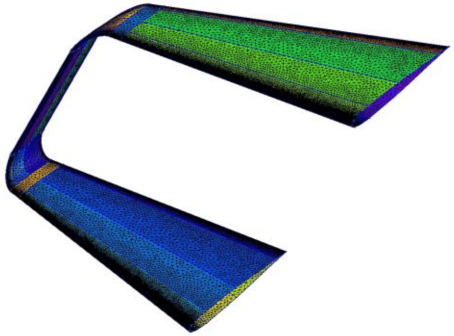


Meshing Module

Based on **GMSH**.

An interface imports the geometries, and associates parameter specified in a dedicated section of the input file (CPACS) to the appropriate regions on the wing surface and domain boundaries.



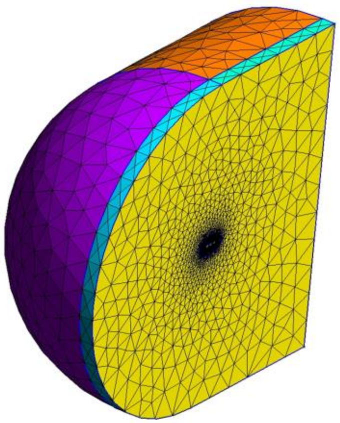


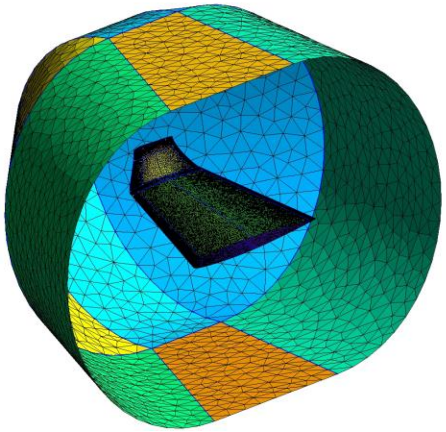
Current fully working

- 2D Euler Mesh
- 2D Rans Mesh
- 3D Euler Mesh

Under development

- 3D RANS mesh
  - Issues with GMSH algorithms if a quality mesh is sought (requirement for SU2 code, and for good results in general).





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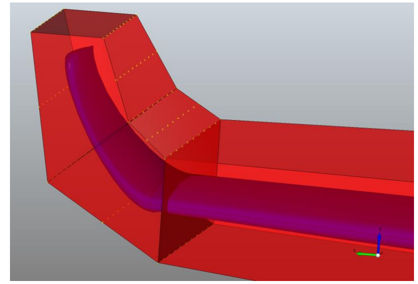
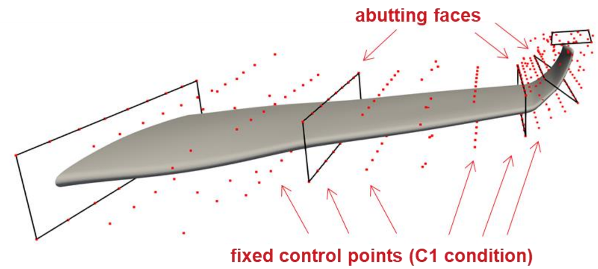
Conclusions and Future Works

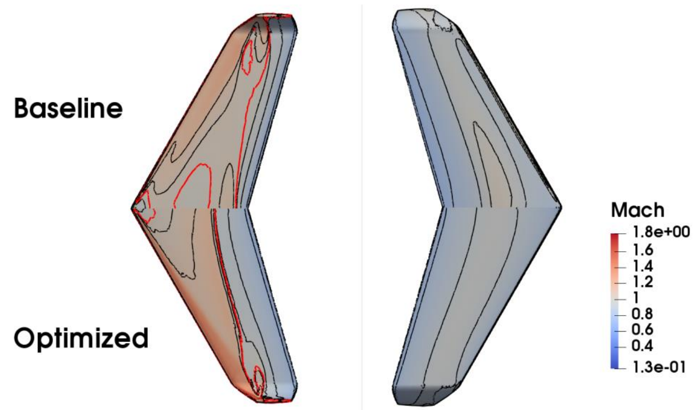
Conclusions

- Modification on SU2 code have been carried out in order to perform aerodynamic shape optimization of nonplanar wings.

- SU2 has been employed inside NERONE, for automatic shape optimization inside an MDAO.



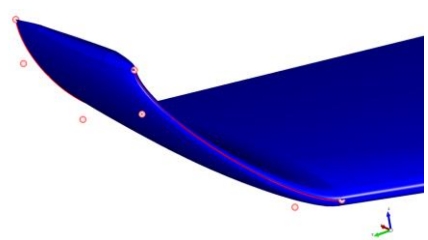


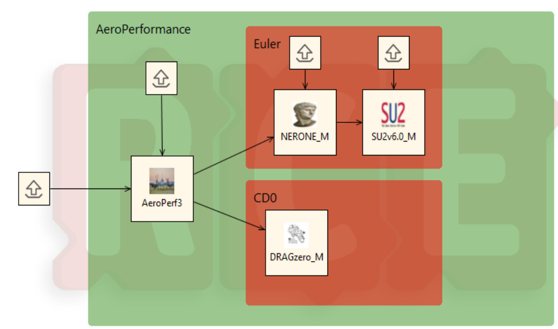


Future Works

- SU2 level:
    - Code “polishing” (comments, comply with SU2-code standard.
    - Add generality.

- NERONE level
    - 3D meshing for RANS





4th Annual SU2 Developers Meeting - May 8-10, 2019

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