Sinus For Ever

30 ans de simulation et optimisation aérodynamique

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HIGHER TOGETHER™

DASSAULT AVIATION

Aerodynamics Optimisation: Gradient computation

State equation $E(\mu, W(\mu)) = 0$

Cost function $j(\mu) = J(\mu, W(\mu))$

Constraints functions $g(\mu) = G(\mu, W(\mu))$

Minimizing $j(\mu)$ *while respecting constraints* $g_i(\mu) \leq 0$

We observe

$$f(\mu) = F(\mu, W(\mu)) = \left(J(\mu, W(\mu)), G(\mu, W(\mu))\right)$$

$$\mu = (v, l)$$

with l *= aerodynamic parameters*

and v *= geometric parameters (CAD modeler)*

PDE control theory
J-L Lions
Dunod, 1968

Aerodynamics Optimisation: Gradient computation

To estimate

$\mu = (\nu, l)$

$$\boxed{\begin{aligned} \delta f &= \frac{df(\mu)}{d\mu} \cdot \delta\mu = \frac{dF(\mu, W(\mu))}{d\mu} \cdot \delta\mu \\ \delta f &= \frac{\partial F}{\partial W} \frac{\partial W}{\partial l} \cdot \delta l + \frac{\partial F}{\partial W} \frac{\partial W}{\partial \nu} \cdot \delta\nu + \frac{\partial F}{\partial l} \cdot \delta l + \frac{\partial F}{\partial \nu} \cdot \delta\nu \end{aligned}}$$

- *Thanks to the state equation*

$$E(\mu, W(\mu)) = 0$$

- *and then*

$$\boxed{\delta E(\mu, W(\mu)) = \frac{\partial E}{\partial W} \cdot \delta W + \frac{\partial E}{\partial \mu} \cdot \delta\mu = 0}$$

- *Thanks to the mesh deformation equation*

$$L(d(\nu), D(\nu)) = 0$$

- *and then*

$$\boxed{\delta L(d(\nu), D(\nu)) = \frac{\partial L}{\partial d} \cdot \delta d + \frac{\partial L}{\partial D} \cdot \delta D = 0}$$

Aerodynamics Optimisation: Gradient computation

- *Evaluate variations of the Lagrangian* $\delta f^* = \delta f - \Psi(\mu)^T \delta E - \Phi(\nu)^T \delta L$
- *with*

$$\left(\frac{\partial E}{\partial W}\left(l, D(\nu), W(\mu)\right)\right)^T \Psi(\mu) = \left[\frac{\partial F}{\partial W}\left(\mu, W(\mu)\right)\right]^T$$

$$\frac{\partial F}{\partial D}\left(l, D(\nu), W(\mu)\right) - \Psi^T \frac{\partial E}{\partial D}\left(l, D(\nu), W(\mu)\right) = \Phi^T \frac{\partial L}{\partial D}\left(d(\nu), D(\nu)\right)$$

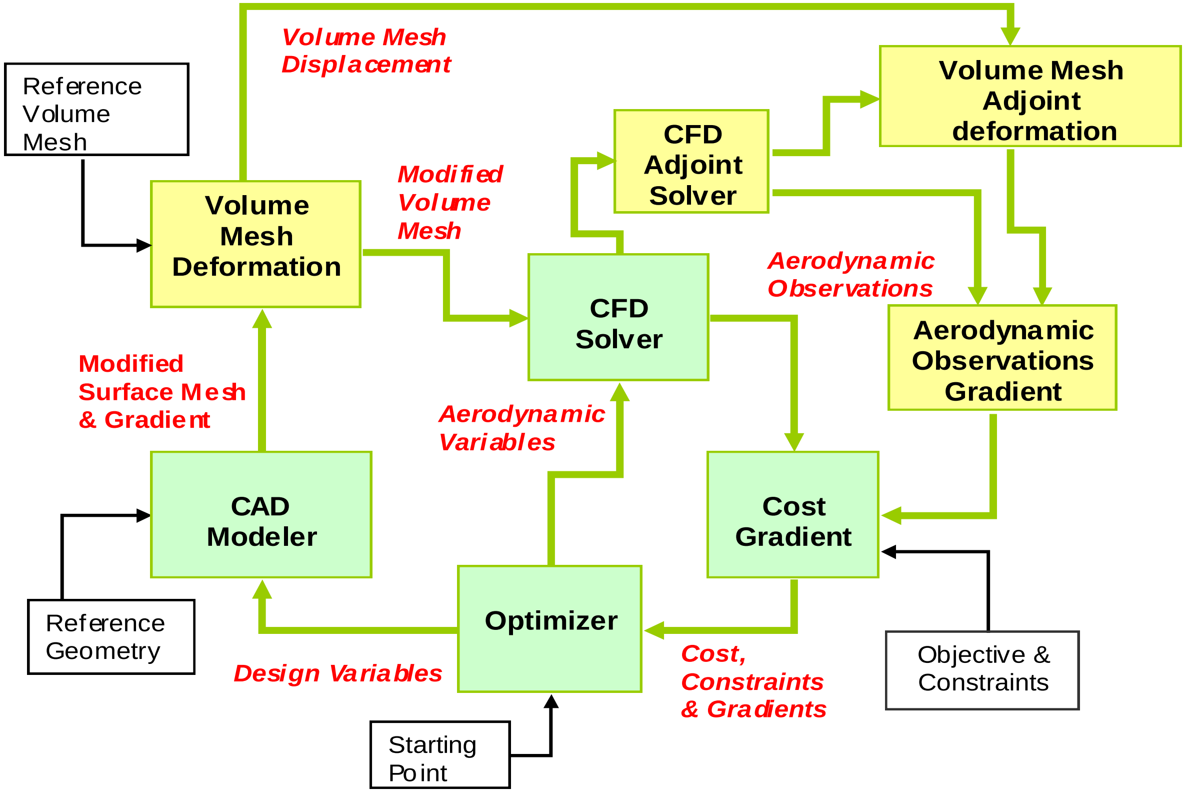
- *to obtain*

$$\begin{cases} \dfrac{dF}{dl} = \dfrac{\partial F}{\partial l} - \Psi^T \left[\dfrac{\partial E}{\partial l}\right] \\ \dfrac{dF}{d\nu} = -\Phi^T \left[\dfrac{\partial L}{\partial d} \dfrac{\partial d}{\partial \nu}\right] \end{cases}$$

Automatic shape optimization (1/5)
Introduction

- Complex process : large effort to develop and mature
- Key ingredients:
  - Adjoint approach including mesh motion
  - Parameterization (CAD + features)
  - Extensive library of cost functions

- Process progressively applied to many real life design problems
  - Strong interaction with design team to define relevant formulation of the problem

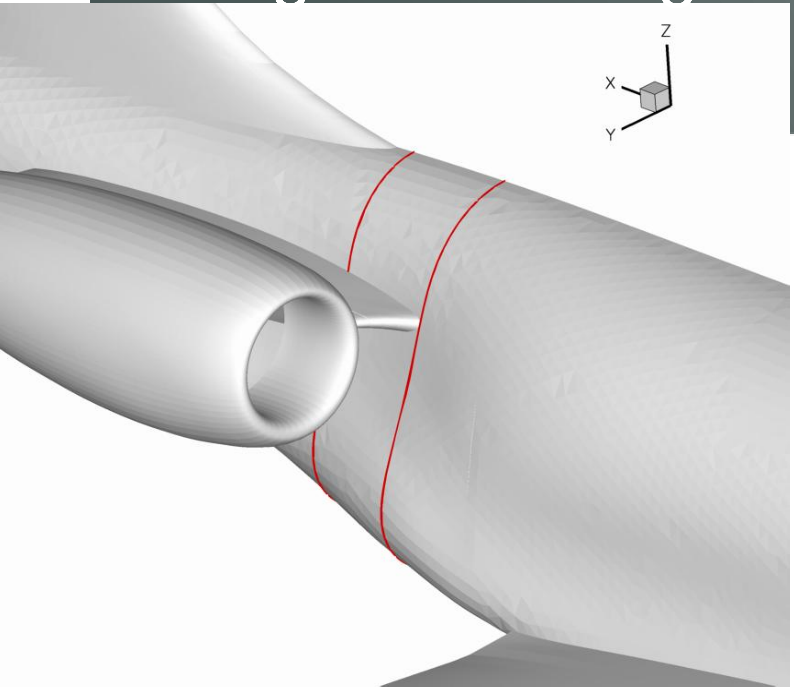


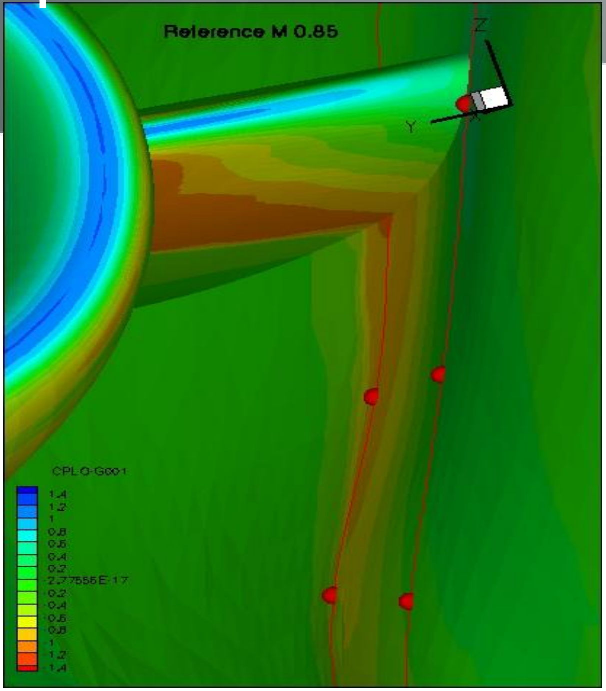
Aerodynamics Optimisation: Optimization techniques

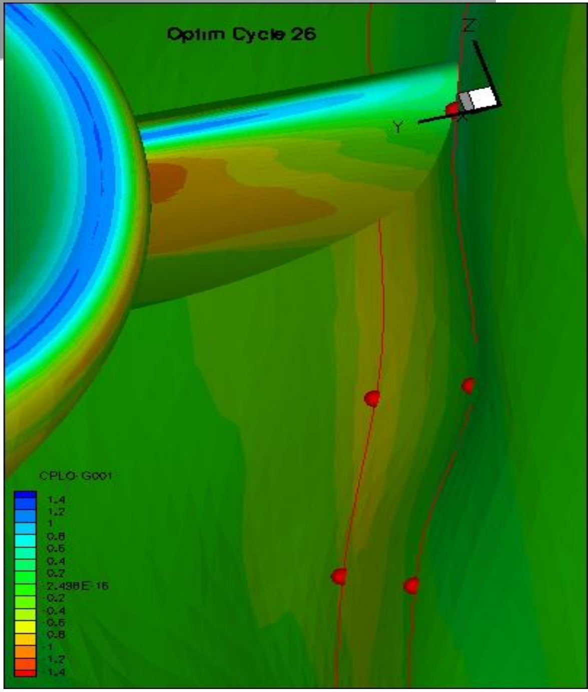
Automatic Differentiation software Tapenade (INRIA-Sophia-Antipolis).

Gradient-based optimization
Feasible (direction) Sequential Quadratic Programming
Feasible Arc Interior Point Algorithm (FAIPA) developed by Prof. J.N. Herskovits & co-workers

Aerodynamics Optimisation: Design of fuselage shape







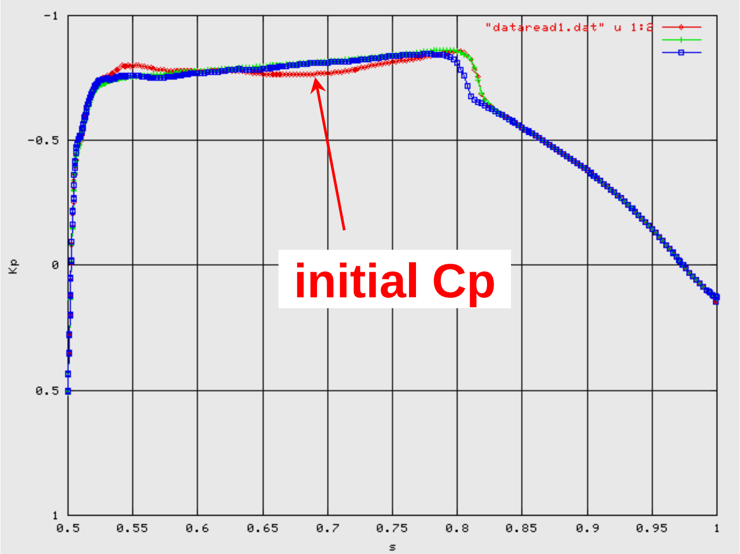
Optimization based on 3D Navier-Stokes

- *Large degree of automatisation required for the design of a complex area*
  - *Complex aerodynamics*
  - *Fully 3D shape design*
  - *Trade off with internal layout*

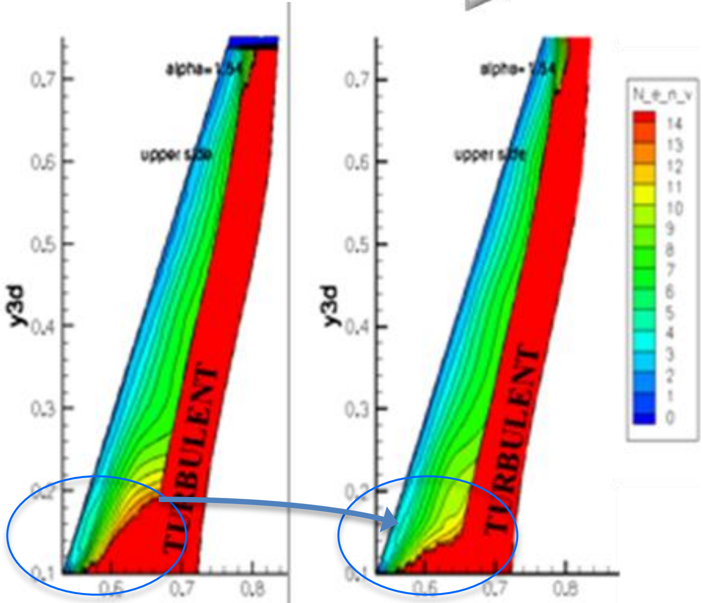
Automatic shape optimization (2/5)

Laminar wing optimization to increase laminar area on wing next to the fuselage

- Laminar wing, Φ = 20°
- Mach = 0.75, angle of attack= 3°
- Objective : increase laminar area on wing next to the fuselage → Cp & δCp/δx target locally
- Leeward wing section profile
- Navier-Stokes with adjoint



Cp(x/c) – Laminar wing



before optimization

after optimization

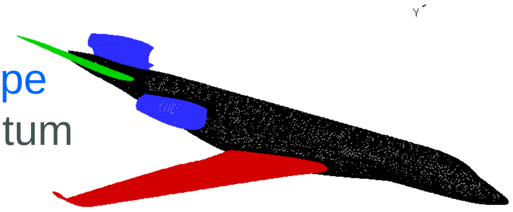
Transition line on leeward side of ECO2 wing

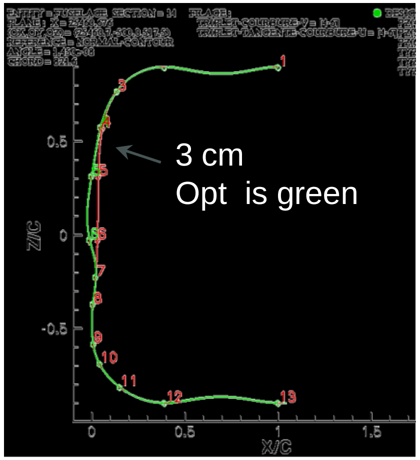
Automatic shape optimization (3/5)

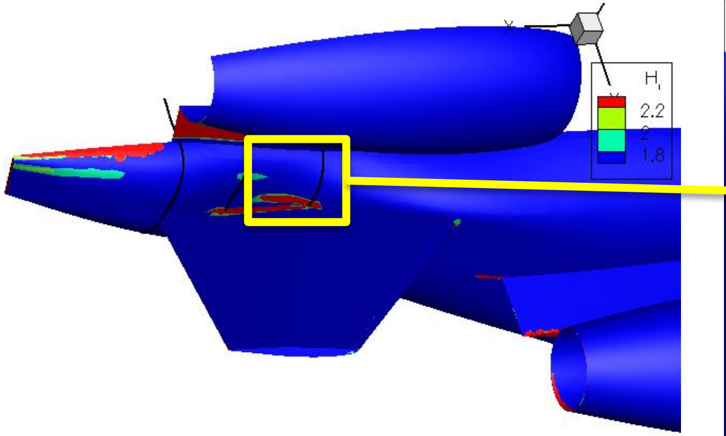
Afterbody optimization of innovative configuration

Example of complex objective functions

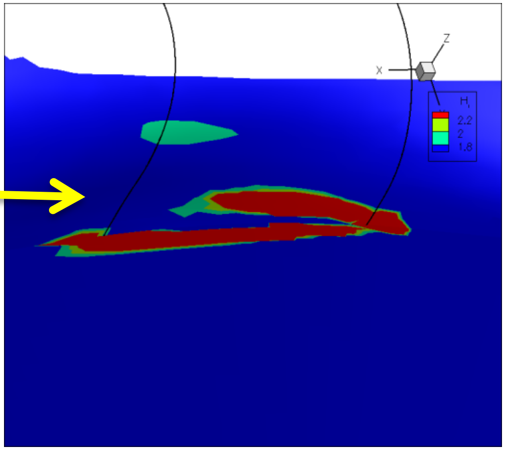
- Mach = 0.85, angle of attack = 1.5°
- Cost function is based on the boundary layer shape parameter Hi (ration of displacement and momentum thickness)
- fuselage shape: 10 variables
- Adjoint approach - Convergence requires about 20 NS computations



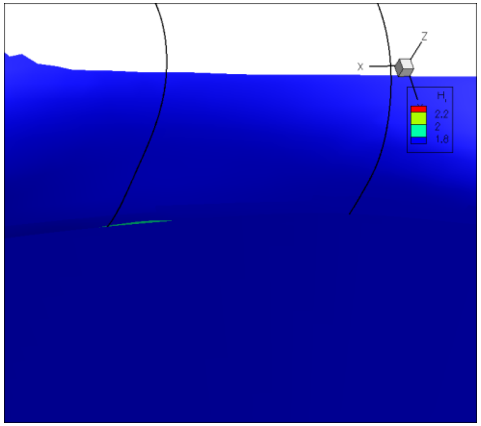




Recirculation zone (Hi>2.2) red

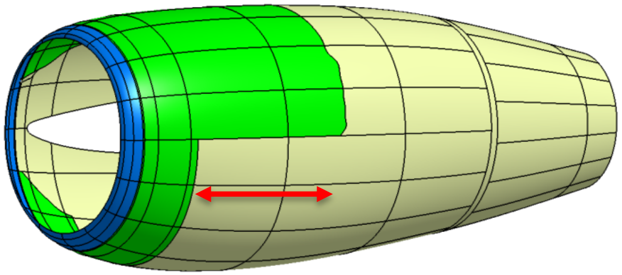


Hi before optimization

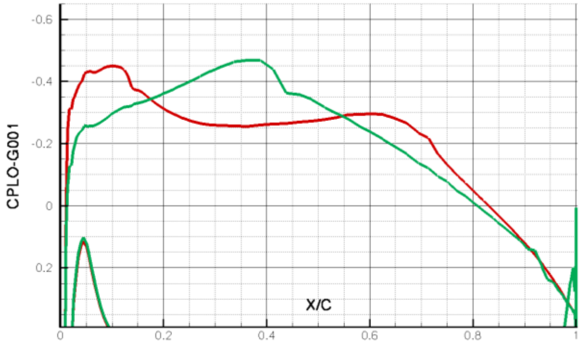


Hi after optimization

Optimisation nacelle laminaire



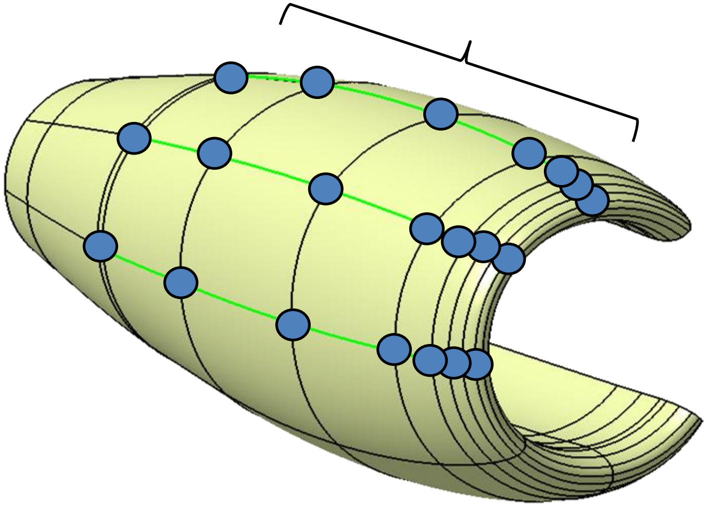
M=0.85, Cz milieu croisière
Gain 1.2% traînée avion



Extension de laminarité sur la partie supérieure d'une nacelle

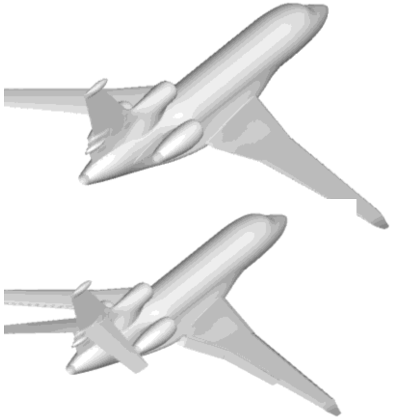
Laminarité ~ 40%

Triplets libérés



Automatic shape optimization (4/5)

Low speed – high speed wing tip optimization

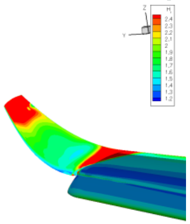


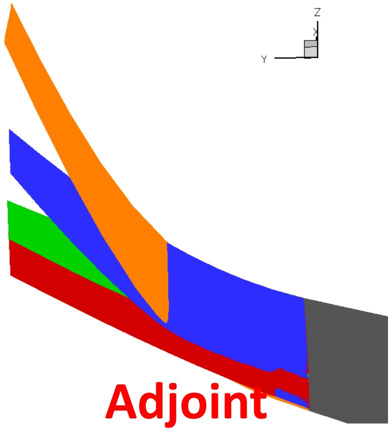
Multipoint optimization : low speed (Mach = 0.18, high lift configuration) – high speed (Mach = 0.8, cruise configuration)

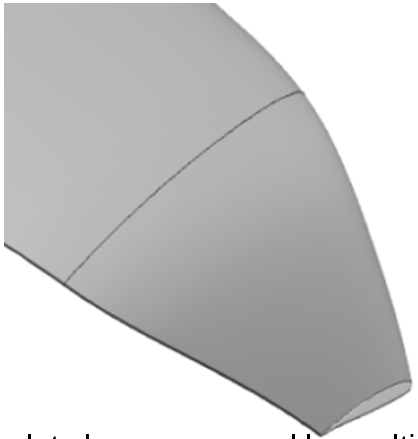
Minimize

- drag at high speed (constraints on lift +trimmed+ bending moment at y = 8 m)
- surface Hi > 2 at low speed

Parameters: aoa (at High speed), twist, sweep angle, dihedral, thickness, span

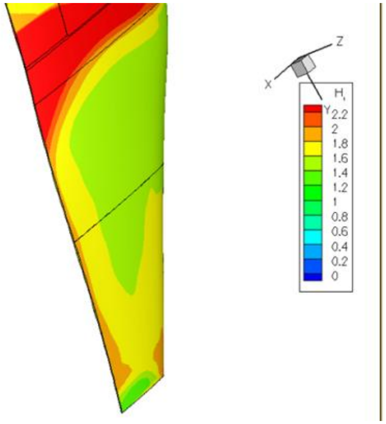






winglet shape proposed by multipoint optimization

1 % reduction of drag

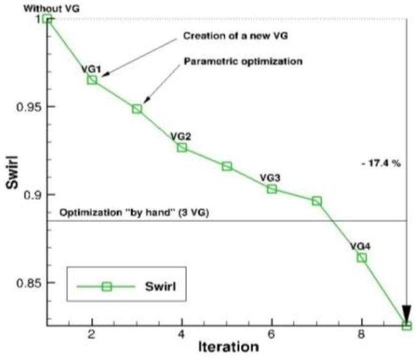


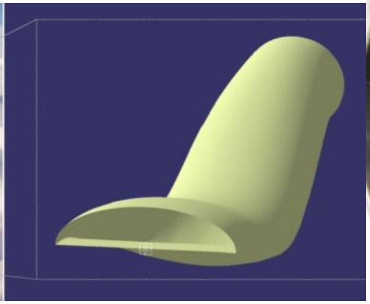
Boundary layer shape factor on the optimized winglet – high lift configuration

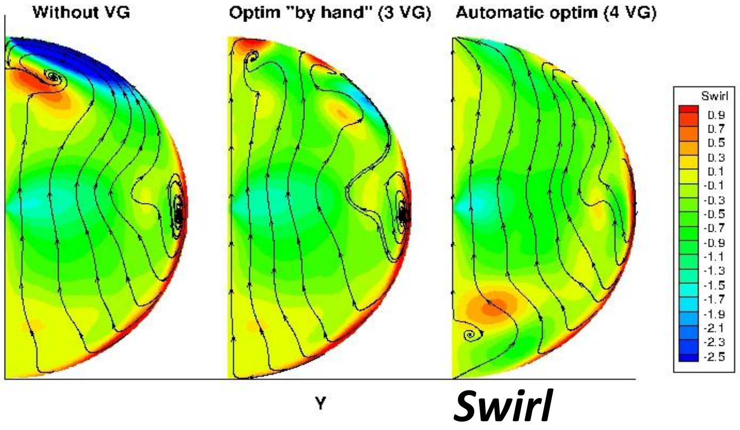
Automatic shape optimization (5/5)

Control and optimization of separated flows

- PhD thesis J. Chetboun : Dassault Aviation / Ecole Polytechnique / DGA.
- Development of automated methods for the control and the optimization of separated flows.
- Application to curved air ducts for UCAV.
- Use of mechanical or fluidic vortex generators (VG)
- Optimization: topological + shape



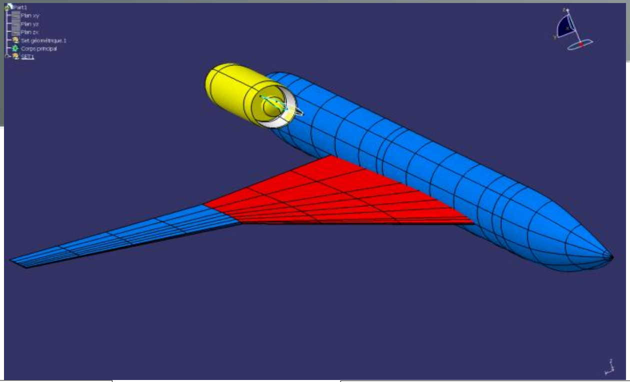




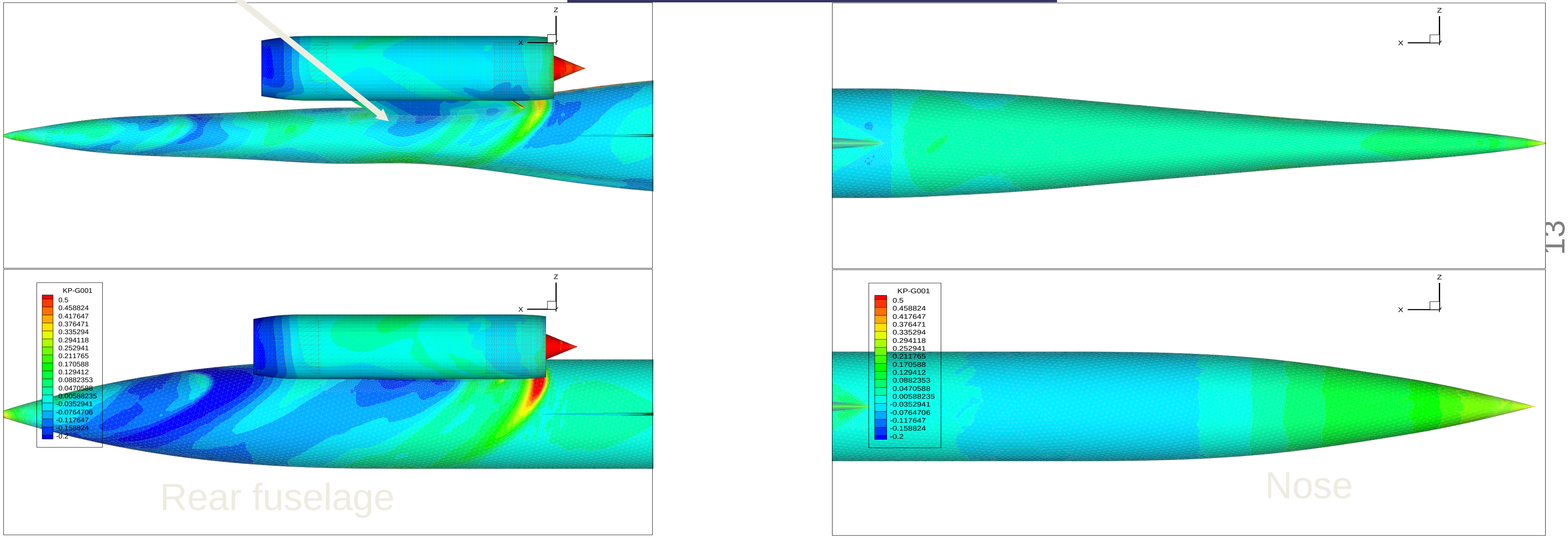
Engine integration optimization

L'optimiseur ne devine pas
les contraintes oubliées

HISAC project (IP - 6th FP)



Gain: 60 %
on zero-lift drag
Sears-Haack …



Cp distribution

Optimization of High Lift configuration within European project DESIREH

(Design, Simulation and Flight Reynolds Number testing for advanced High Lift Solutions)

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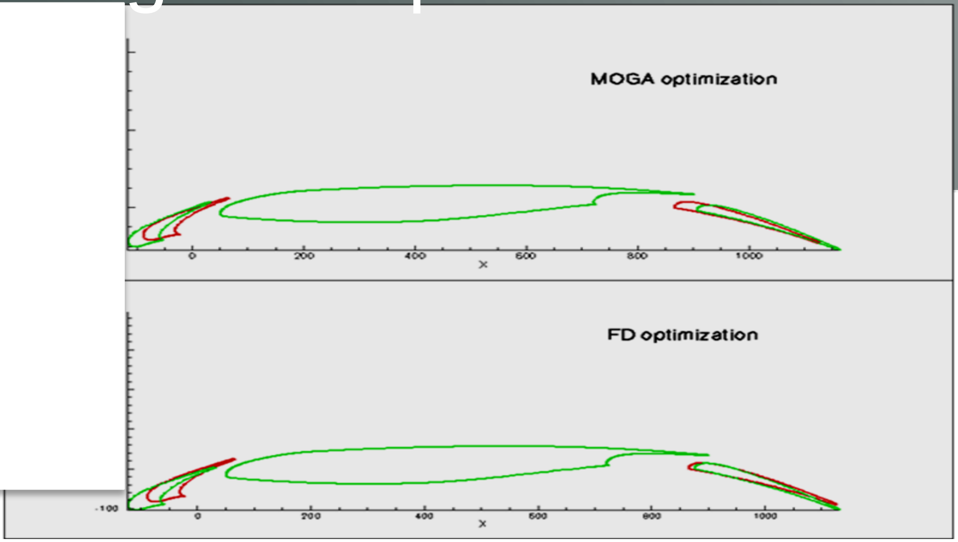
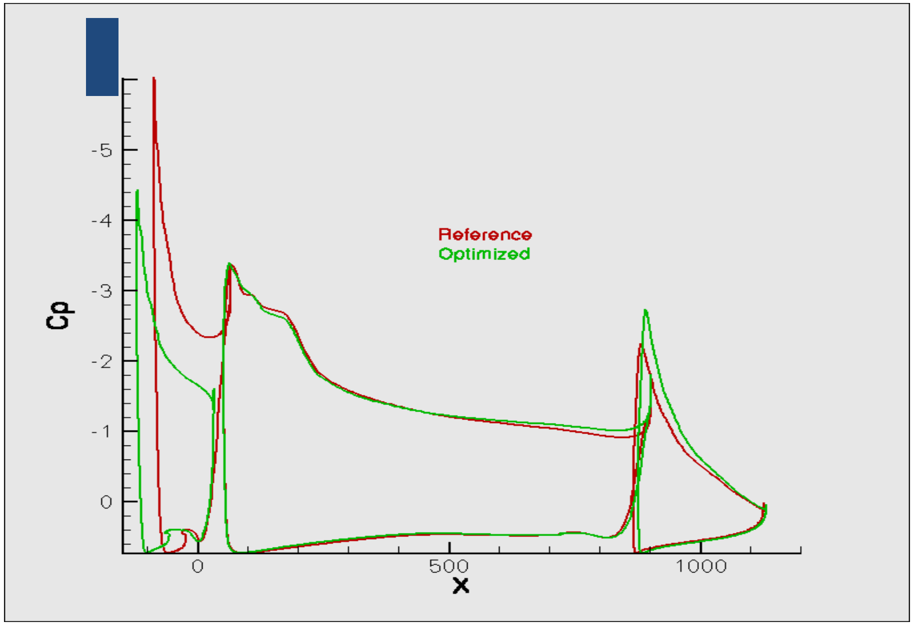
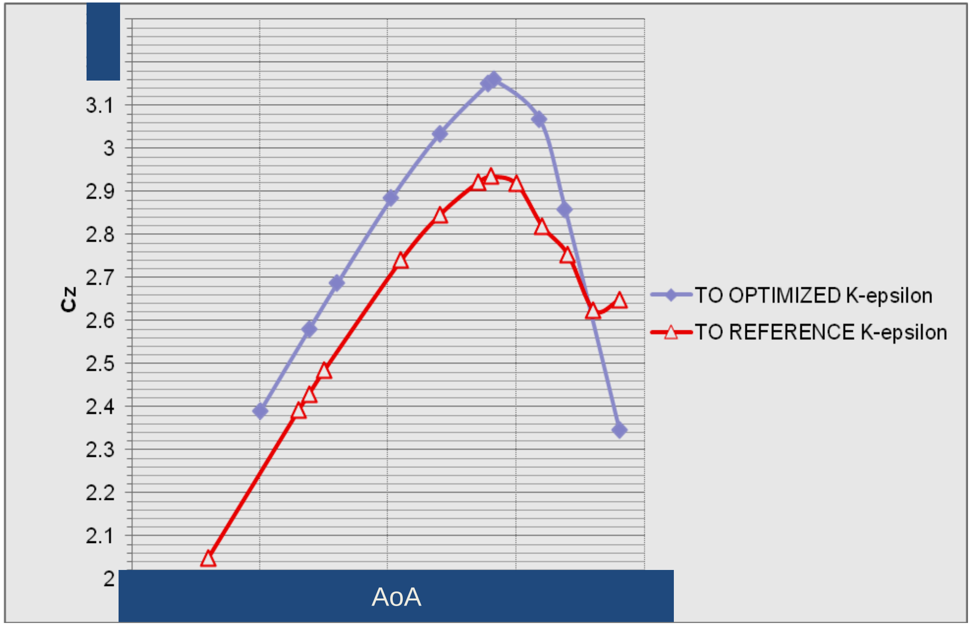
Steven Kleinveld

2.5D High Lift optimization

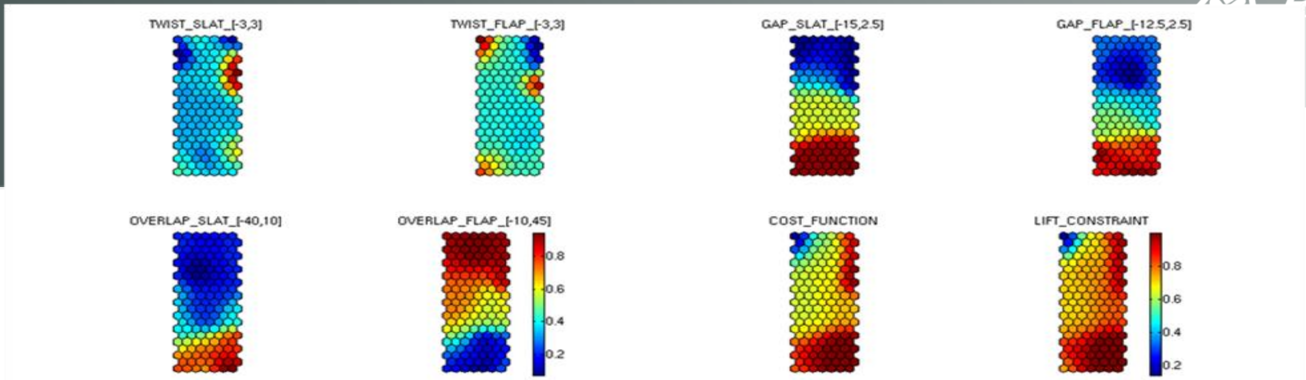


Example of performance improvement through optimization at Take-Off conditions for classical high lift configuration
using setting variables (gap,overlap,deflection angle)





2.5D High Lift optimization

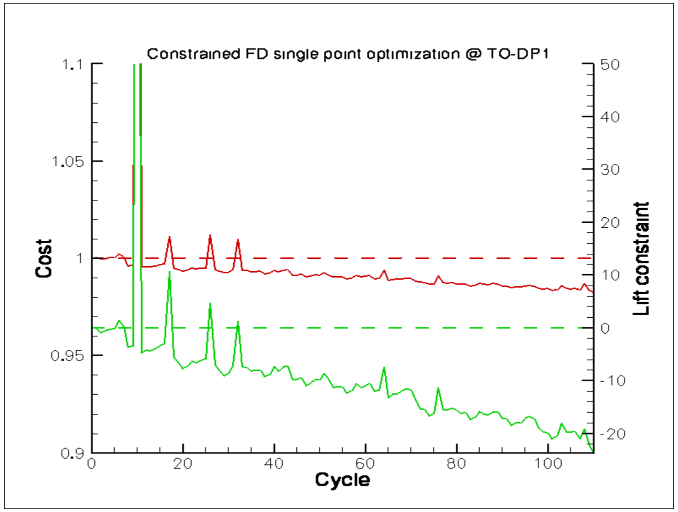


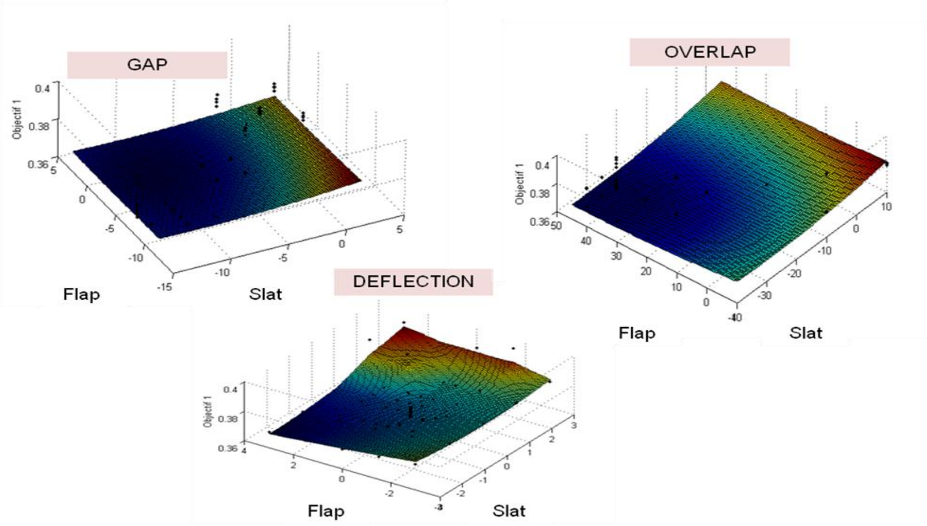
SOM

Use of various techniques to search for improved performance at take-off and landing

FD

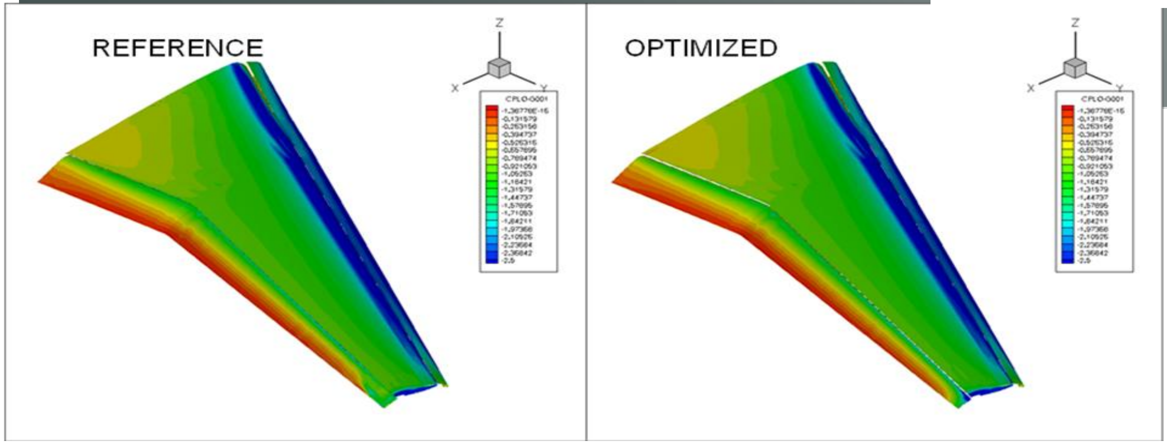
Cost Function $F(x) = F_{reference}(x)$ [≡1]
Lift Constraint $g(x) = 0$ [≡1]

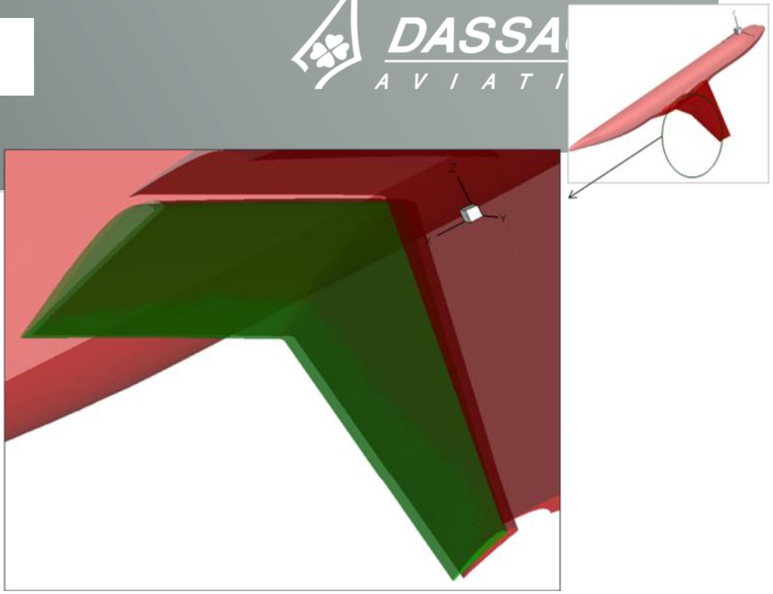




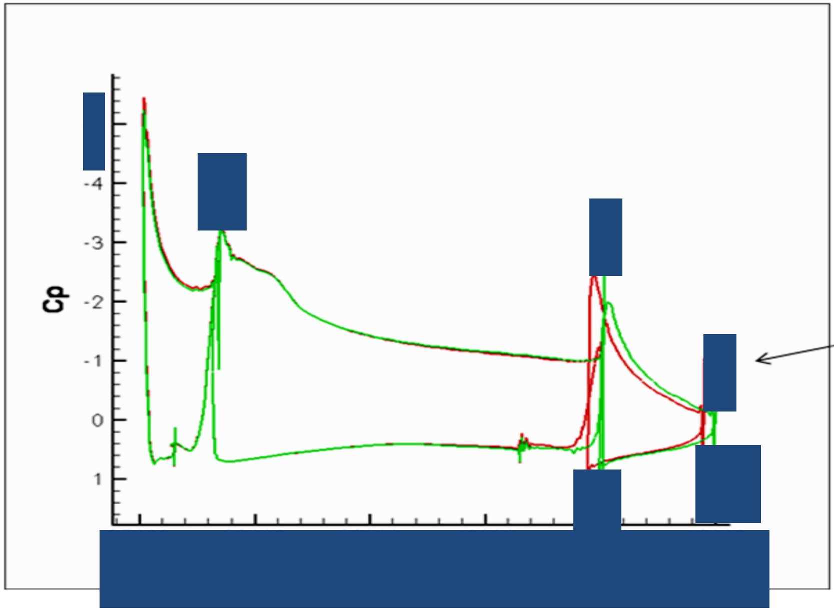
MOGA

3D High Lift optimization





Example of flap position optimization at Take-Off conditions of 3D configuration taking into account variations of the intersection with fuselage



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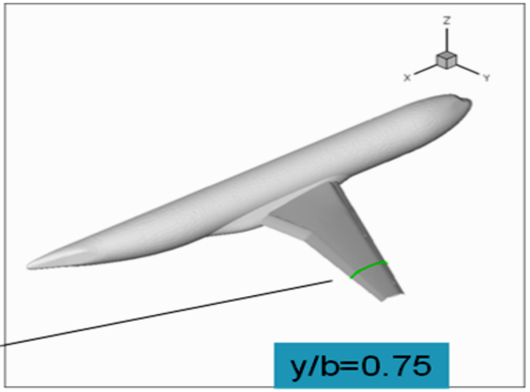
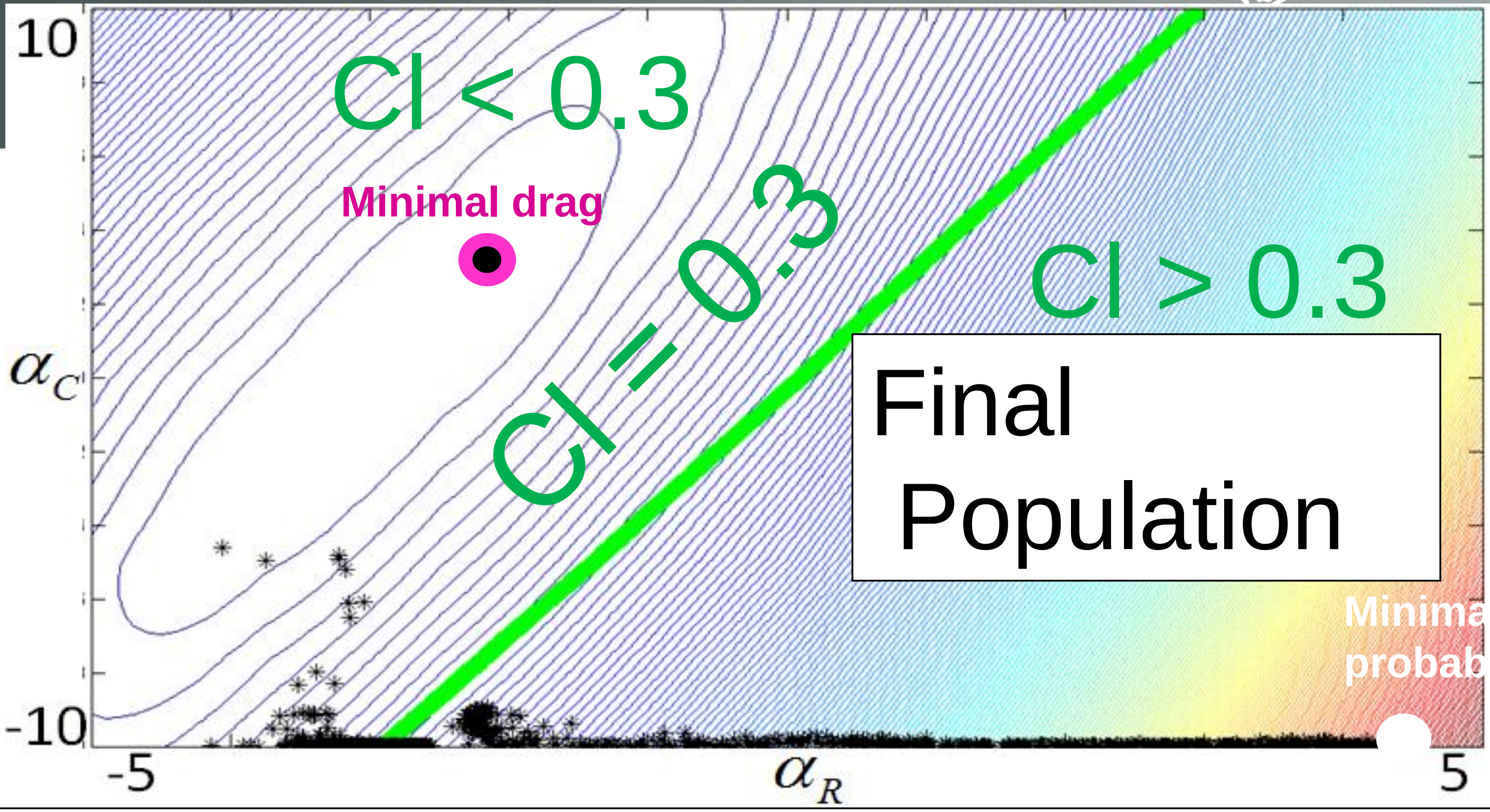


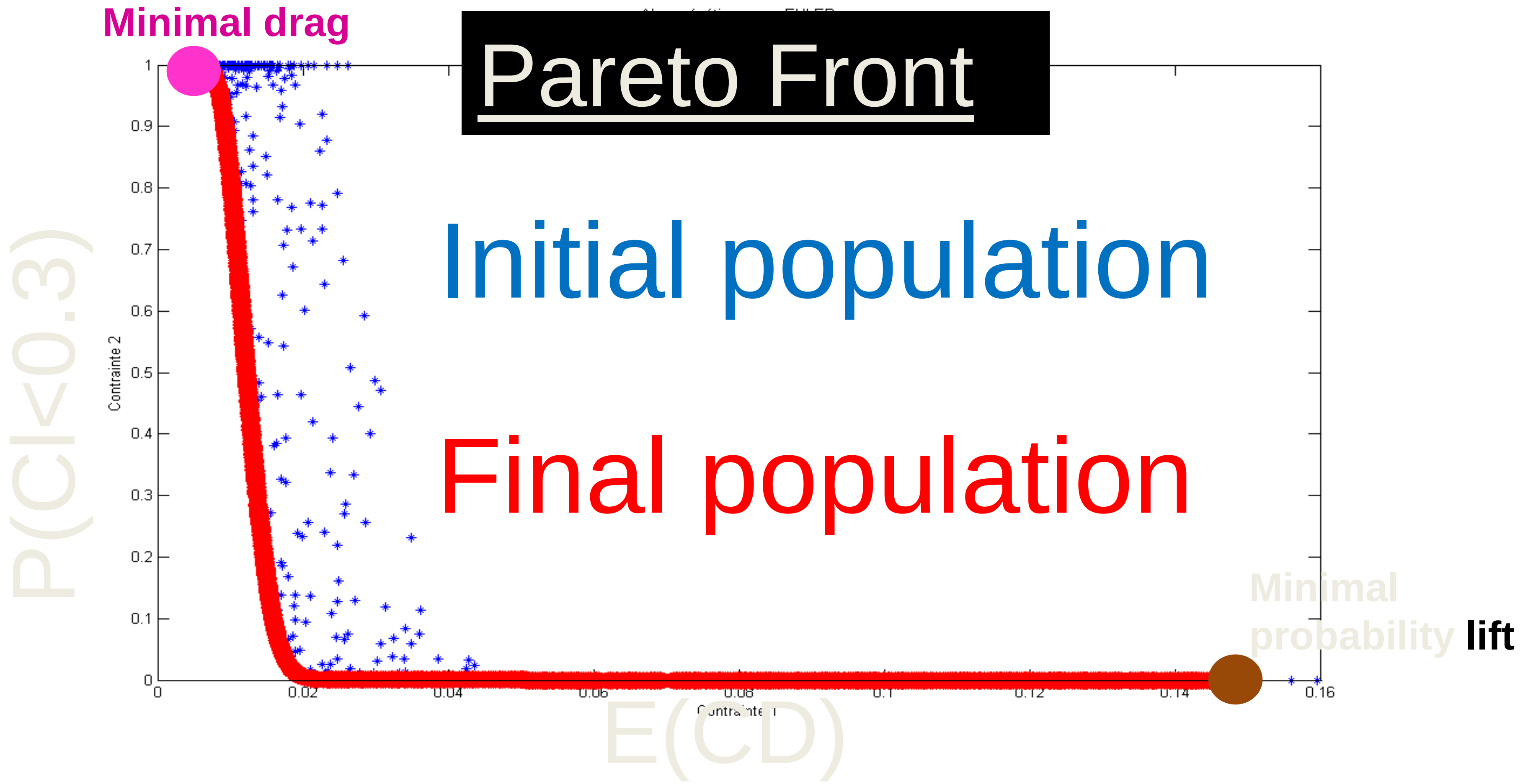
Robust Design (1)



ONERA M6 wing, 2 design parameters: twist and TE camber angles
Euler, RSM RBF like but with 1rst and 2nd derivatives (original approach, Duchon extension)
MOGA, Robust design. Objectives: to control Drag and P(CL<0.3)

Ludovic Martin PhD

Robust Design (2)



Minimal drag

Pareto Front

Initial population

Final population

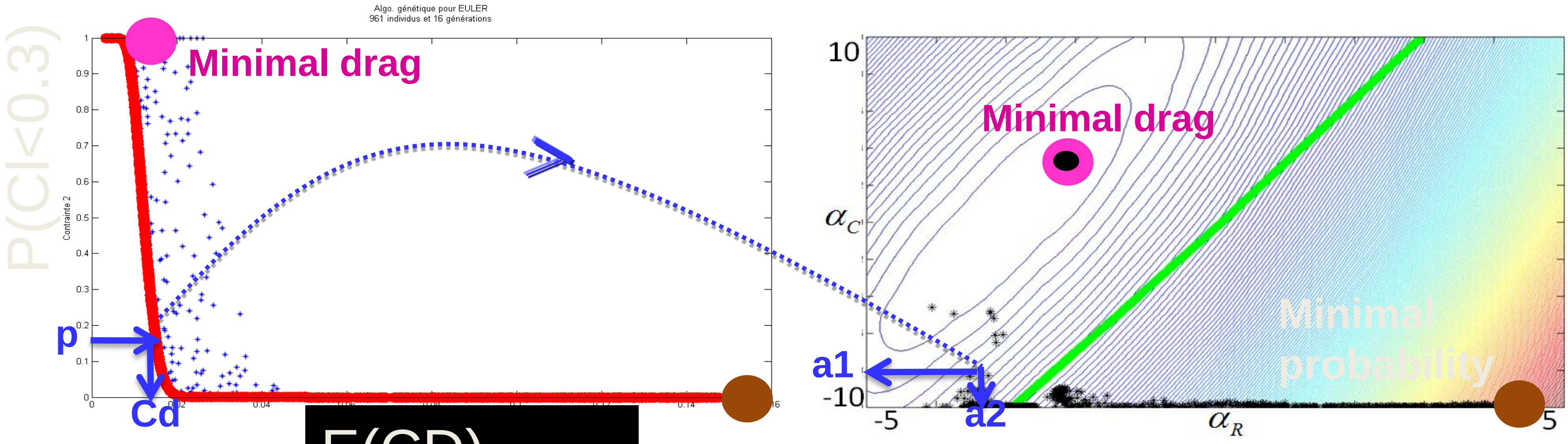
Minimal probability **lift**

Robust Design (3)

Decision: we accept a probability lift of **p = x%** with minimal drag

→ Determination of drag mean **CD** (Pareto front)

→ Determination of nominal values of geomerical parameters **a1** and **a2** (camber and twist angles)



E(CD)

Robustesse – optimisation multipoints

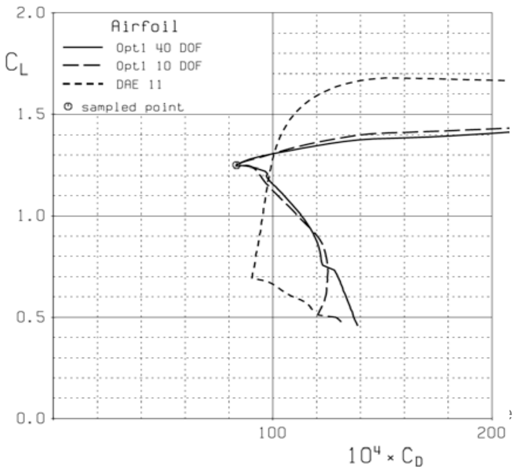
Need for a multi-mission approach

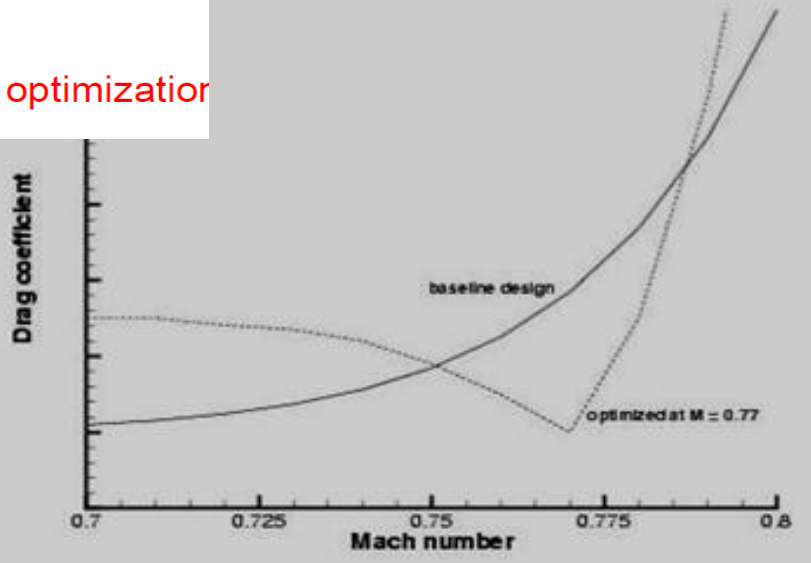
- The aircraft flies multiple missions, which implies
  - Multiple Mach numbers
  - Multiple Reynolds numbers
  - Large mass variations and then Cl variations

- At the aerodynamic design phase, missions are not precisely known

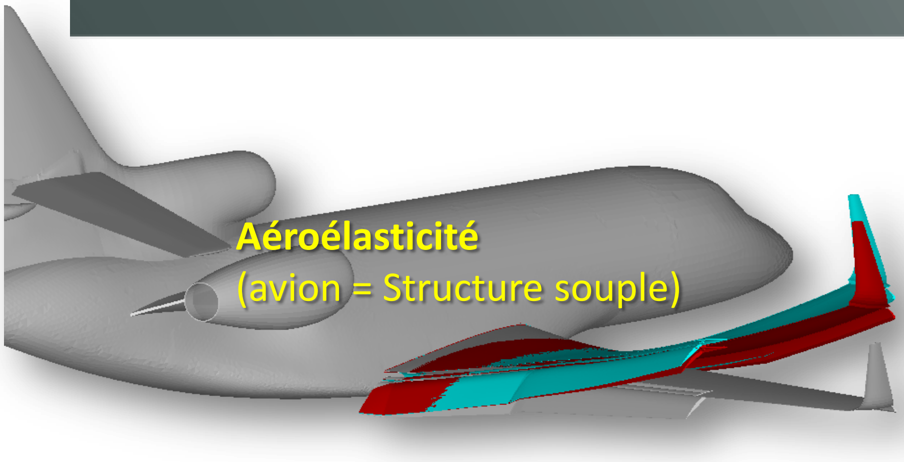
- We know at this step the expected lift, Mach and Reynolds variation ranges

Need for a multi-lift, multi-Mach, multi-Reynolds aerodynamic optimization

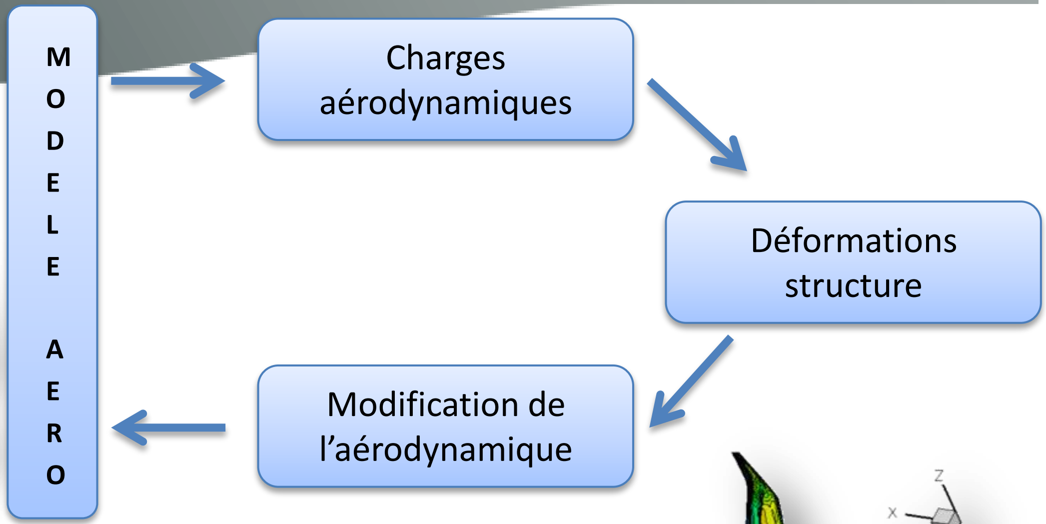




Un domaine en interaction avec les autres disciplines



Aéroélasticité
(avion = Structure souple)



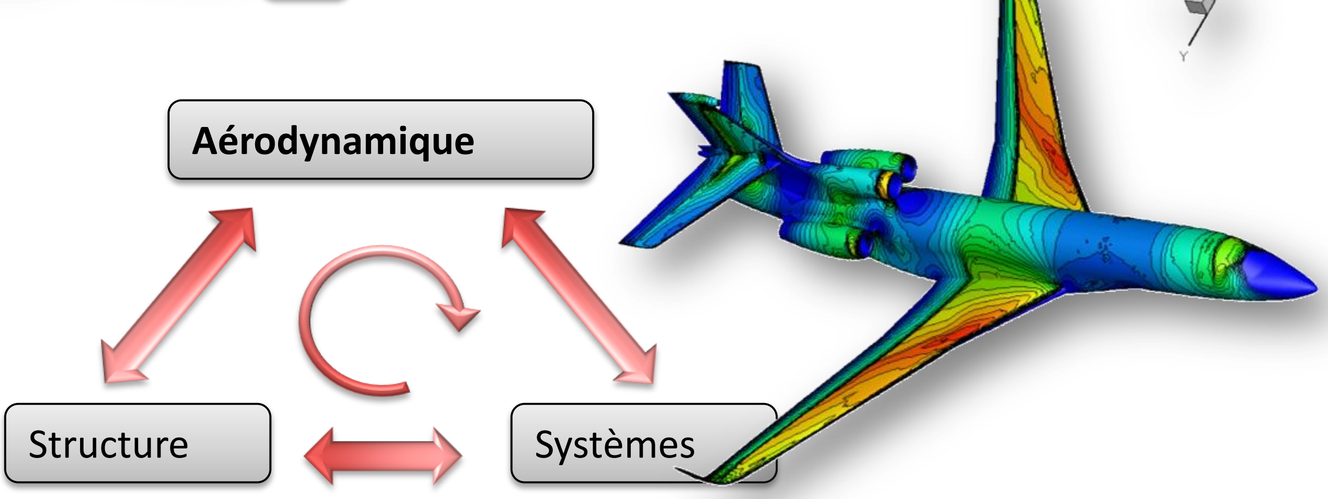
MODELE AERO

Charges aérodynamiques

Déformations structure

Modification de l'aérodynamique

Boucle de conception



Aérodynamique

Structure

Systèmes

Analyse / Optimisation

Euler, Navier-Stokes, Maxwell, élastodynamique

Couplage fluide-structure (aéroelasticité), aéroacoustique, ...

……

Analyse Monodisciplinaire

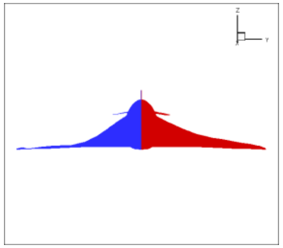
Analyse avec couplage entre 2 disciplines

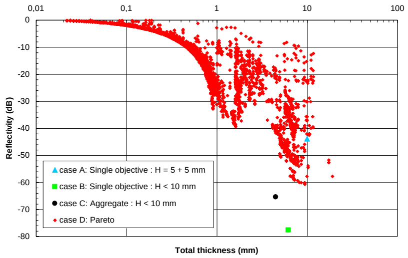
Analyse Multidisciplinaire (MDA)

Optimisation Monodisciplinaire

Optimisation avec couplage entre 2 disciplines

Optimisation Multidisciplinaire (MDO)





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