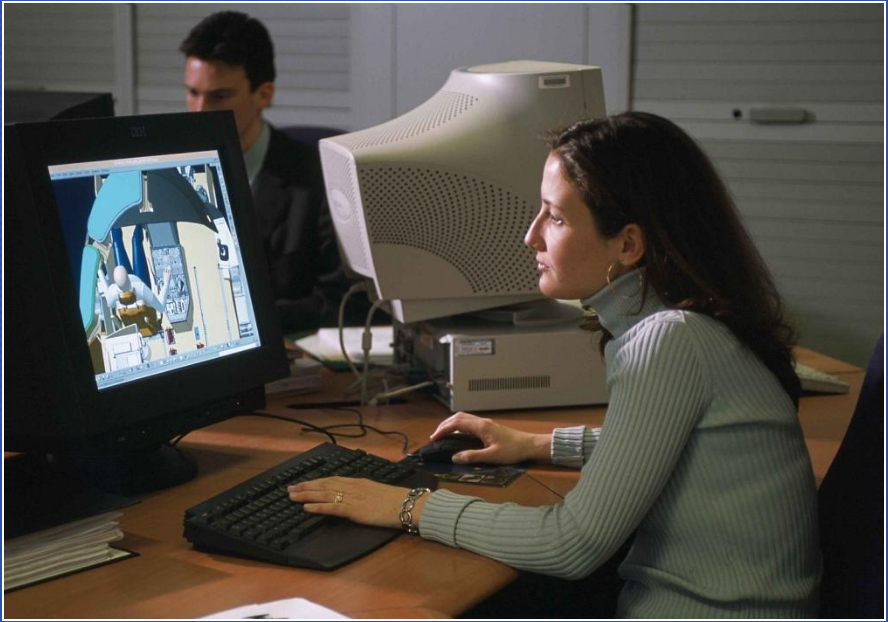
Direction Générale Technique

Shape optimization for aerodynamic design: Dassault Aviation challenges and new trends



Forum TERATEC 2014

Atelier « Conception numérique optimale des systèmes complexes : état de l'art et verrous technologiques »

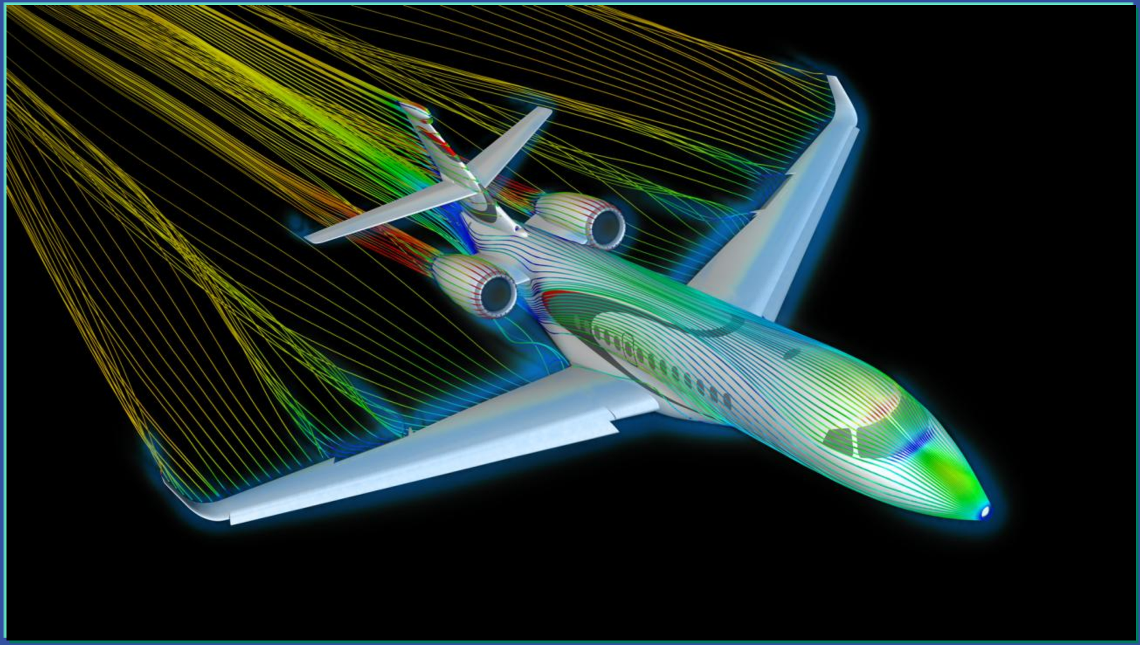
École Polytechnique - Palaiseau- France - July 2nd 2014

DASSAULT AVIATION

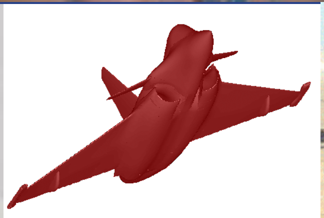
VA OÙ TON RÊVE TE PORTE

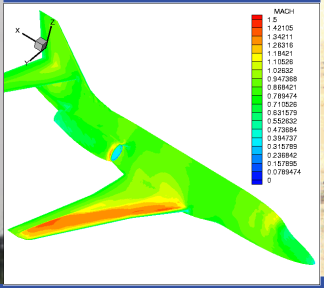
CFD Optimization Team

- Frédéric Chalot
- Laurent Daumas
- Quang Dinh
- Steven Kleinveld
- Ximun Loyatho
- Gilbert Rogé




Civil > 50 %
Falcon 7X

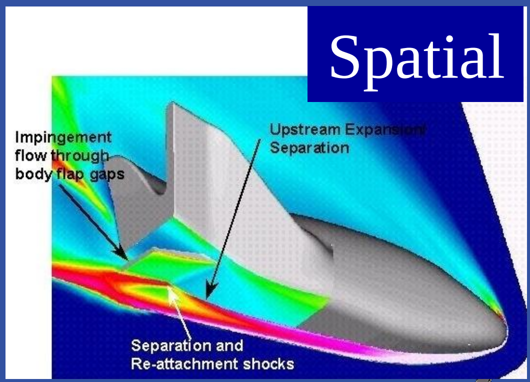





Rafale

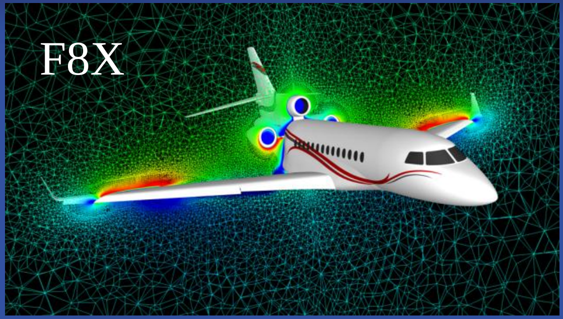

UAV
NEURON

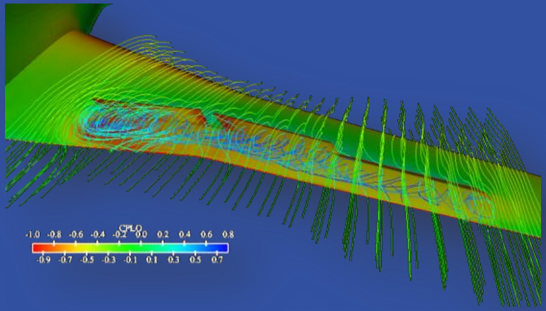

8 2 2002

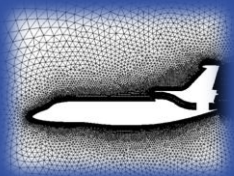

Spatial
Impingement flow through body flap gaps
Upstream Expansion Separation
Separation and Re-attachment shocks

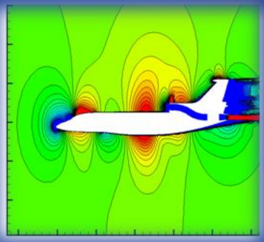
Outline

- *CFD Aerodynamic Shape Optimization in the framework of Aircraft Design*
- *Control Theory, Adjoint, AD*
- *SBJ, Sonic Boom, Engine Integration*
- *High Lift Configuration*
- *Air Duct, Topology + Sizing Opt, Unsteady*
- *New Trends*







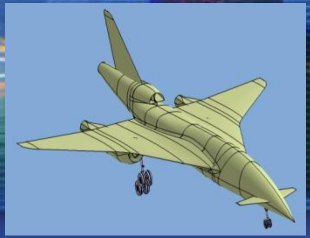


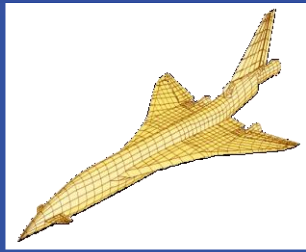
Abstract: The aim of this talk is to discuss various cutting edge techniques developed for the aerodynamic shape optimization of Dassault Aviation future products.

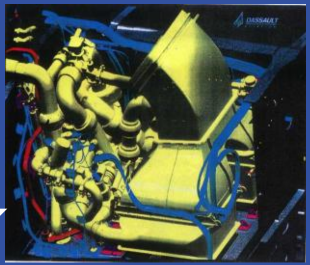
MDO: Multidisciplinarity and Multi-level

MDO: The art of efficiently managing the design parameters between disciplines and levels

level 1 → level 2 → level 3

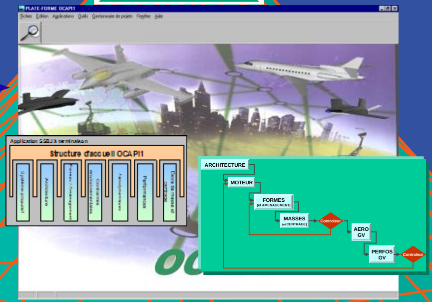






Level 1

Global Optimization,
Comparative assessments
Trade off studies

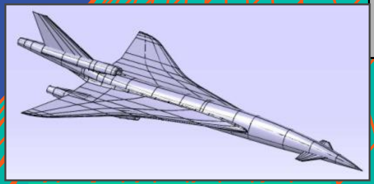


Open framework
Surrogate models

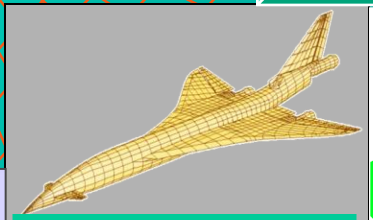
Level 2 & 3

Local Optimization
Critical point investigation
Quantitative assessments

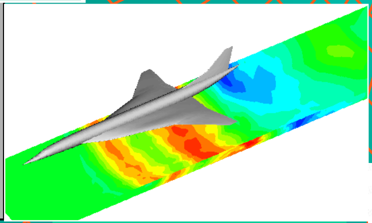
Fine analysis



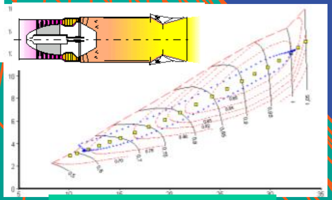
Layout
(icl. certfication issues)



Airframe
(icl. weight estimation, aeroelasticity optimisation)

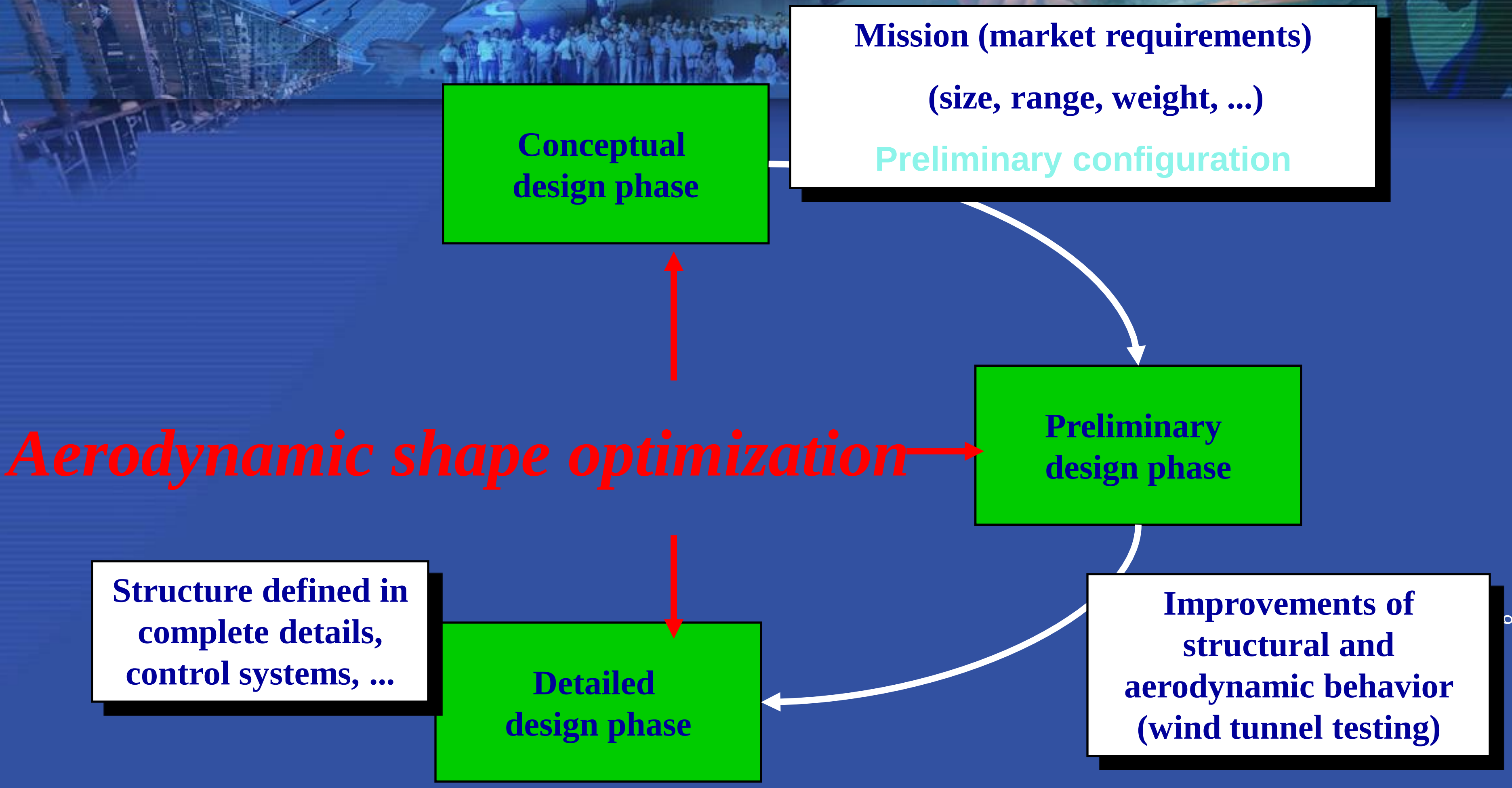


Aerodynamics & Sonic Boom

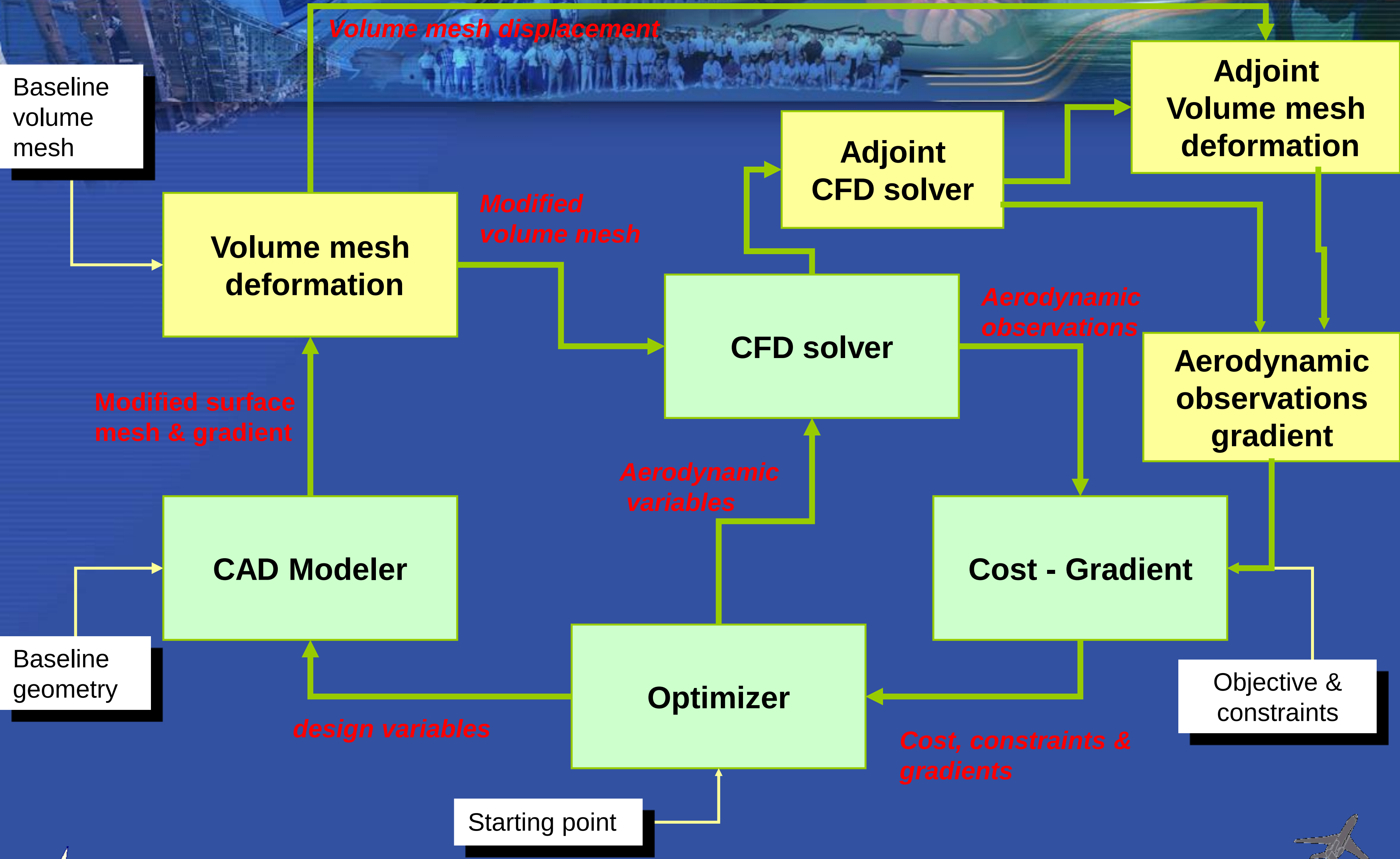


Engine cycle

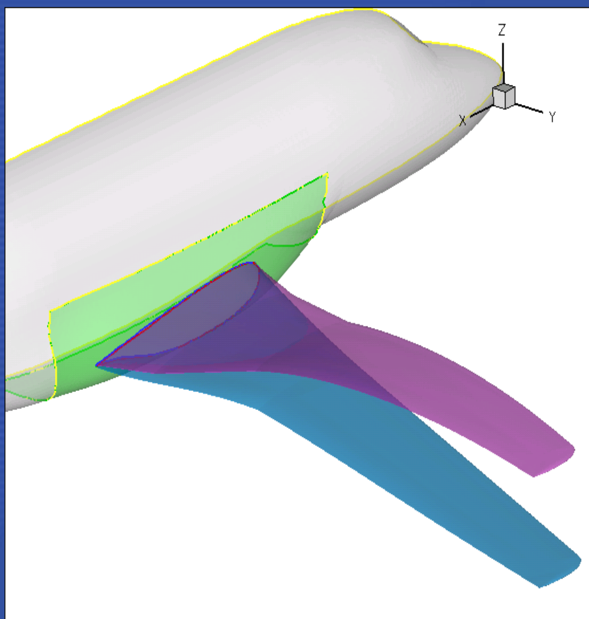
Airplane design cycle



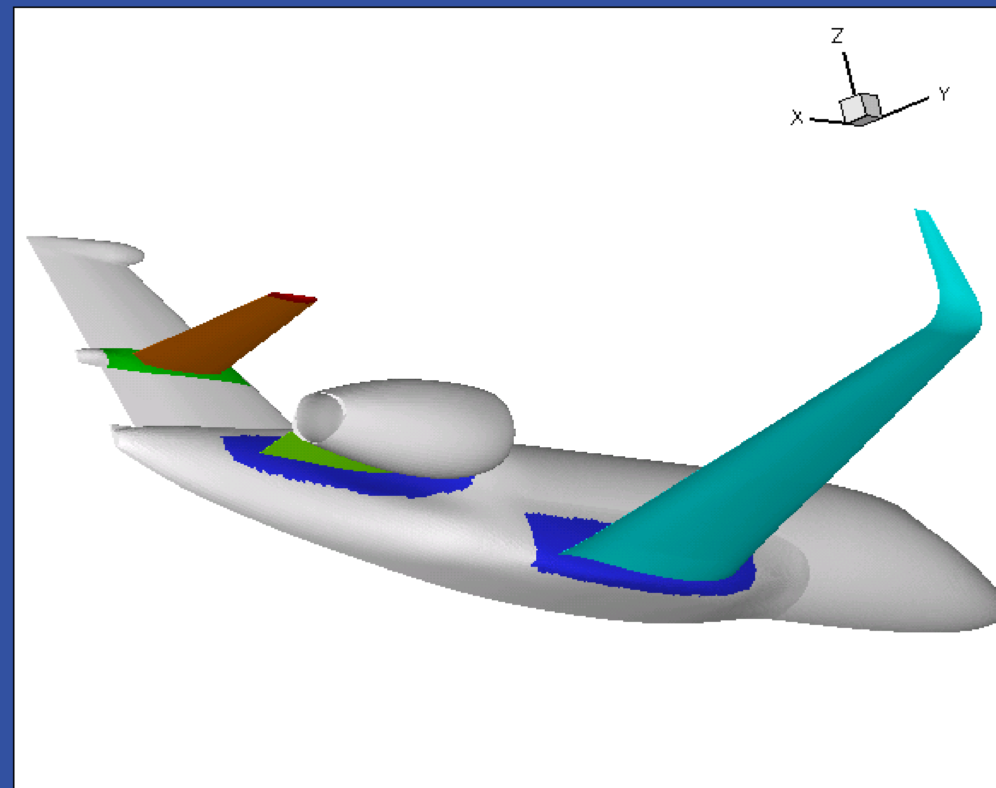
Optimization Process



Geometric Modeller

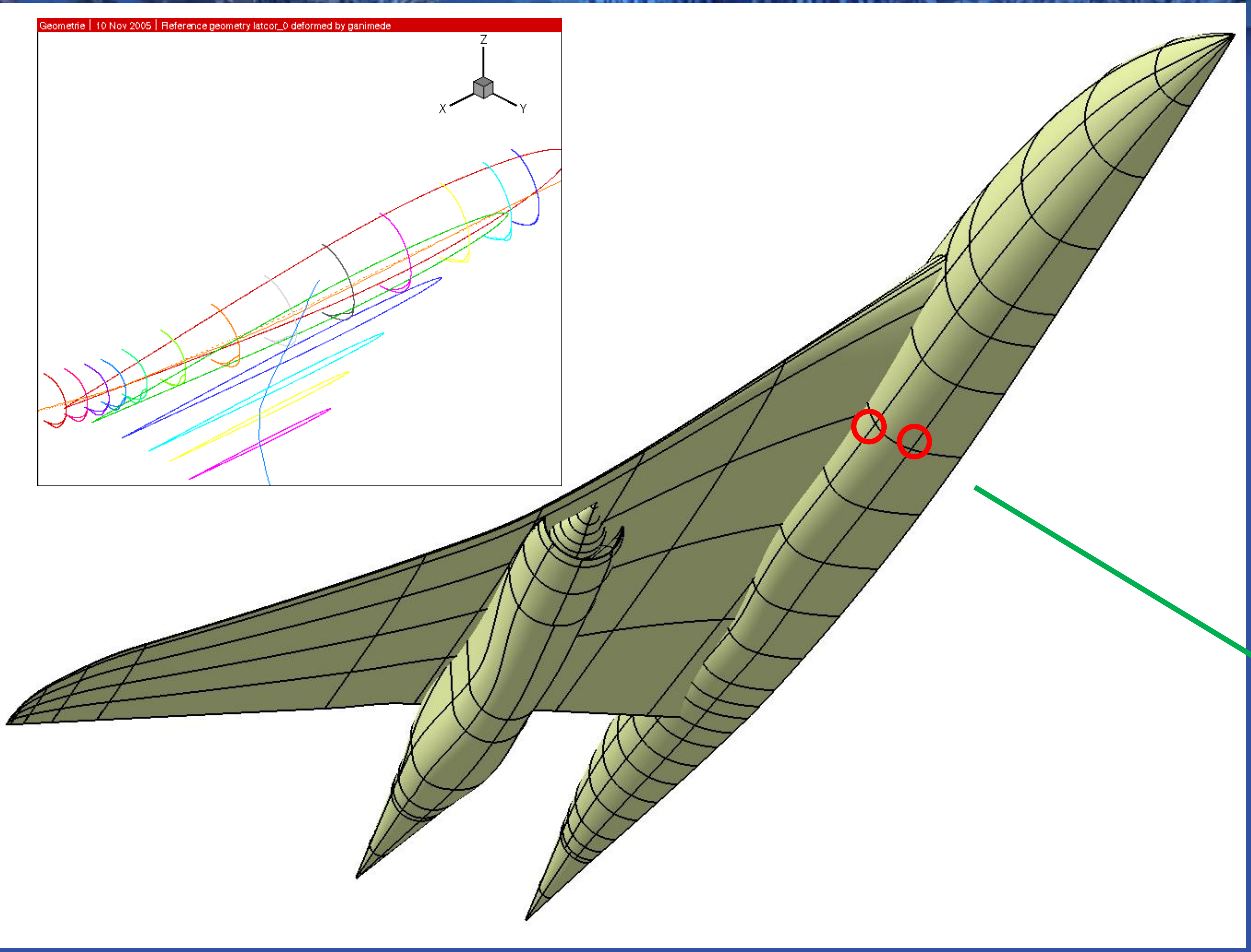


Large deformation

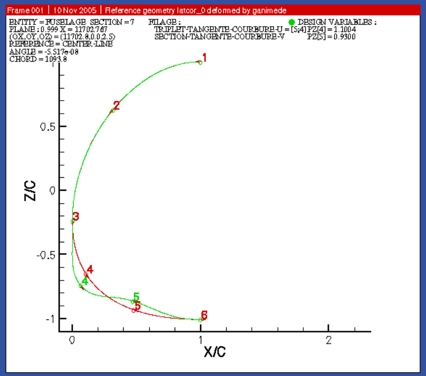


Intersection.
Untrimmed surfaces.

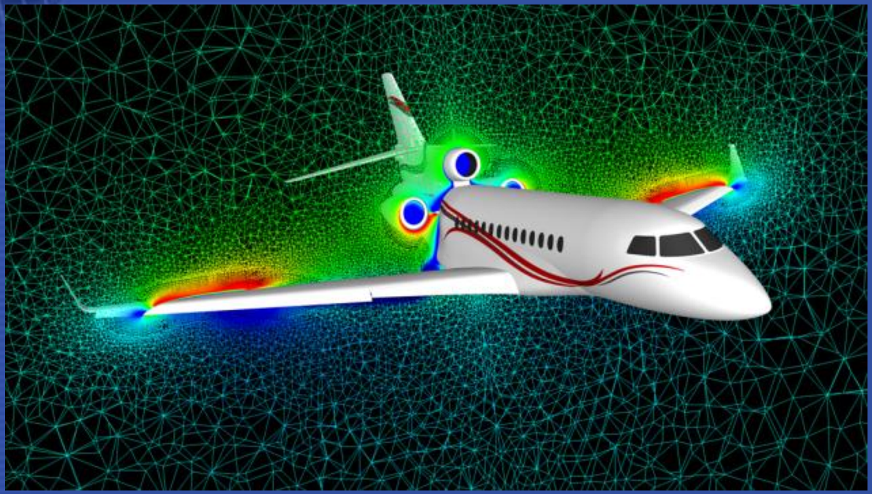
Geometric Modeller

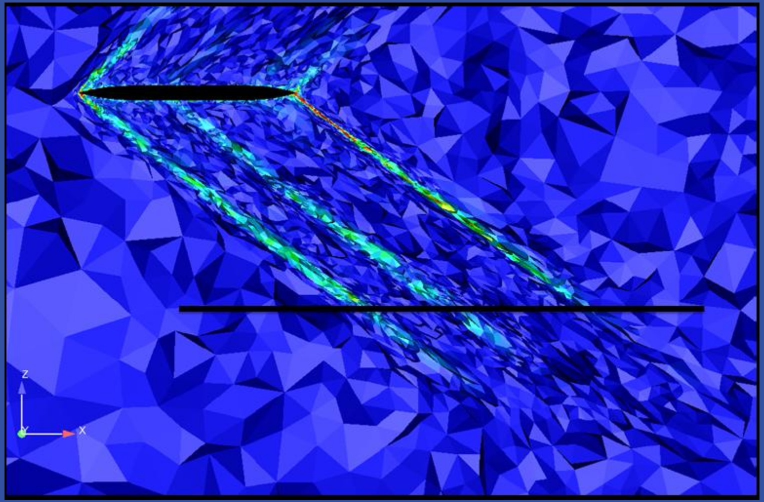


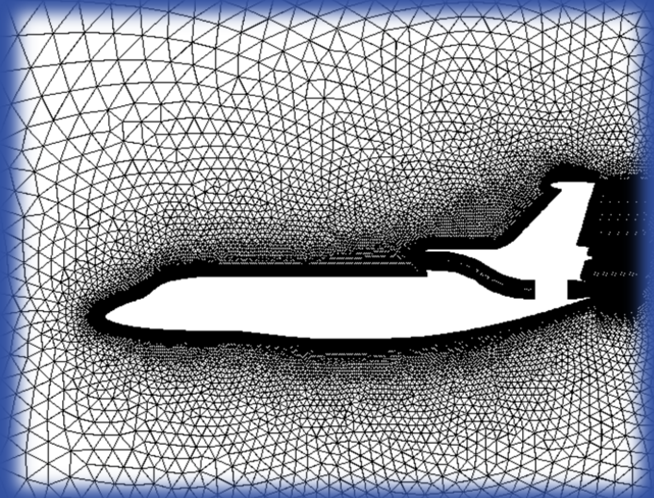
Shape (e.g. fuselage)
Osculator parameters: point, tangent, curvature



Unstructured Meshes

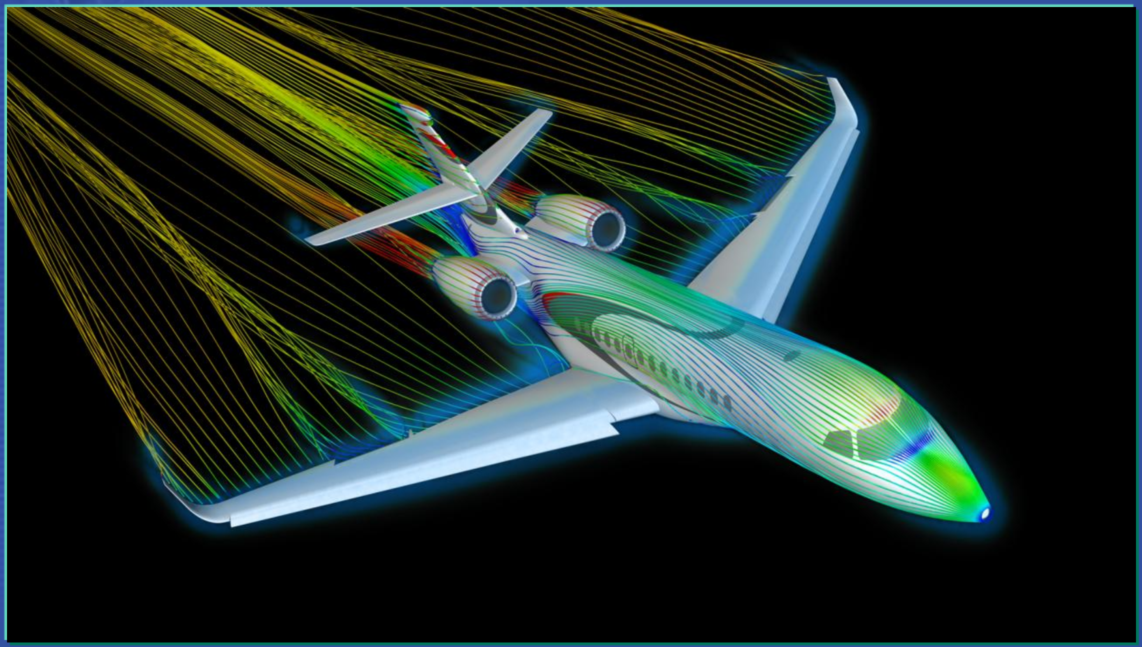


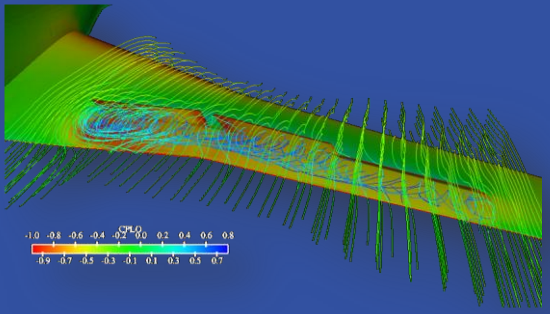


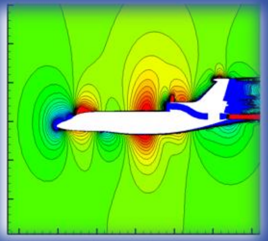


y+=1
~ 10 Millions vertices
~ 60 Millions tetrahedral elements

Navier-Stokes solver







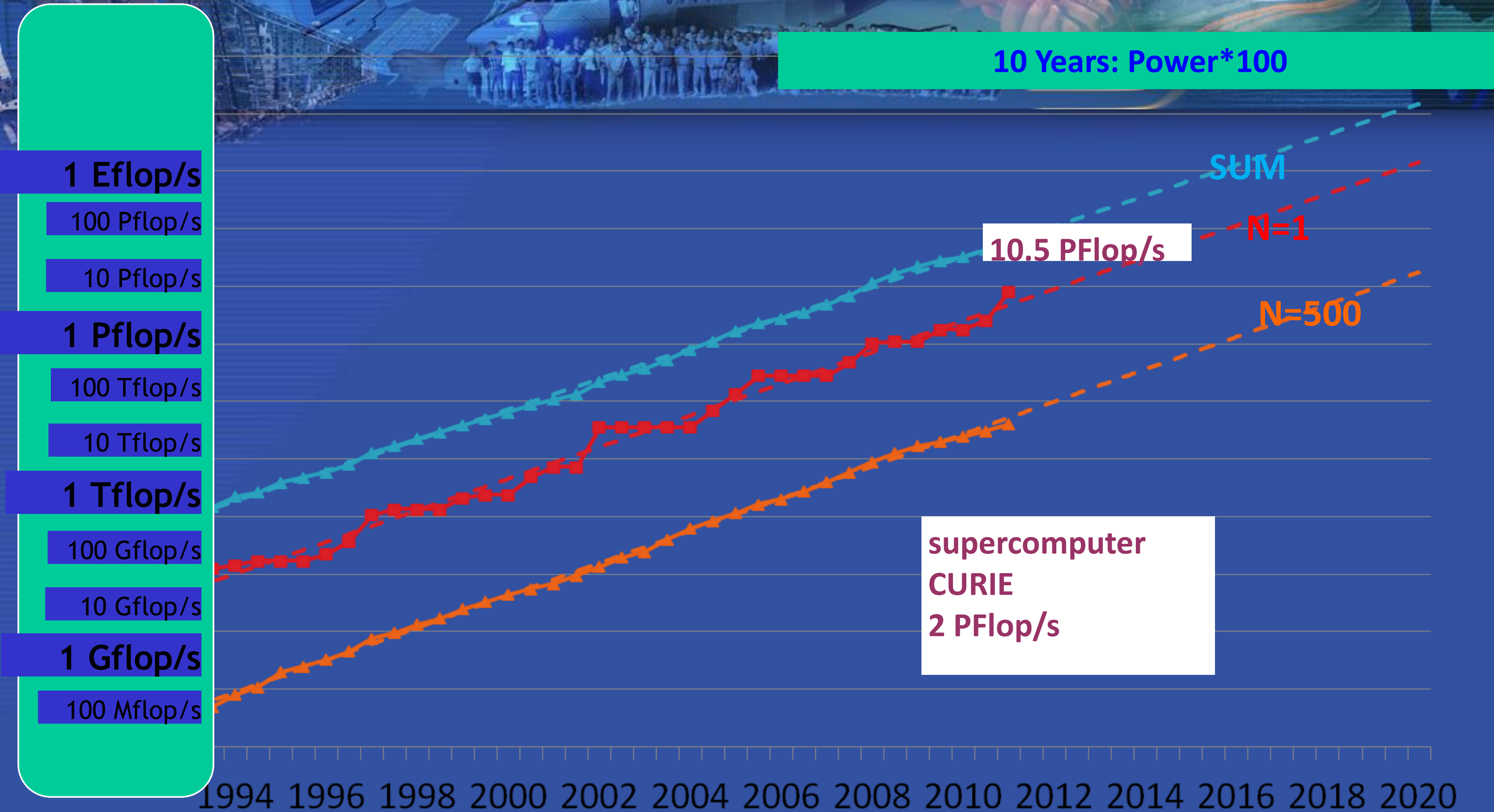
RANS, GLS, entropic variables, implicit scheme, GMRES

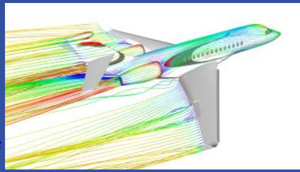
Turbulence modeling: k-epsilon, k-omega, DRSM, …

10 Millions vertices: 20mn on Purflex 512 procs

Tera 10^{12}
Peta 10^{15}

Performance Development





Dassault Aviation follows Moore law

MPI, OPENMP, GPU acceleration

DASSAULT AVIATION

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Implementation strategy

Formulation for derivatives 1 et 2

PDE control theory
J-L Lions
Dunod, 1968

Notations:

E Non linear system for fluid (Euler or Navier-Stokes)

L Linear system for mesh deformation

W State, solution of E

X Volume coordinates

x Surface coordinates

J Observation

λ Aerodynamic parameters

ν Geometric parameters

ψ Fluid Adjoint, solution of $\psi^T \frac{\partial E}{\partial W} = \frac{\partial J}{\partial W}$

ϕ Mesh Adjoint, solution of $\phi^T \frac{\partial L}{\partial X} = \frac{\partial J}{\partial X} - \psi^T \frac{\partial E}{\partial X}$

Second derivative operator

$$D^2_{G_1,G_2} M.[V_1,V_2] = V_1^T \frac{\partial^2 M}{\partial G_1^2} V_1 + 2V_1^T \frac{\partial^2 M}{\partial G_1 \partial G_2} V_2 + V_2^T \frac{\partial^2 M}{\partial G_2^2} V_2$$

Implementation strategy

Formulation for derivatives 1 et 2

$$\frac{dJ}{d\lambda} = \frac{\partial J}{\partial \lambda} - \psi^T \frac{\partial E}{\partial \lambda}$$

$$\frac{d^2 J}{d\lambda^2} = D^2_{W,\lambda} J.[\frac{\partial W}{\partial \lambda},1] - \psi^T D^2_{W,\lambda} E.[\frac{\partial W}{\partial \lambda},1]$$

Explicit — Implicit CFD

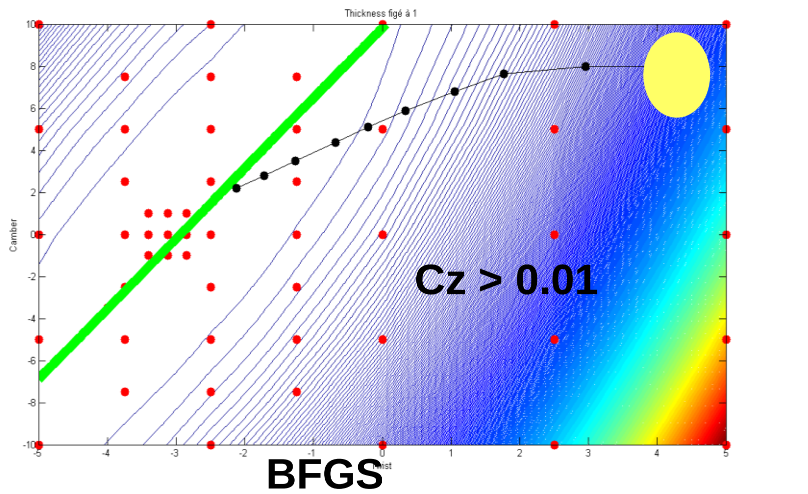
$$\frac{dJ}{d\upsilon} = -\phi^T \frac{\partial L}{\partial x}\frac{\partial x}{\partial \upsilon}$$

$$\frac{d^2 J}{d\upsilon^2} = D^2_{W,X} J.[\frac{\partial W}{\partial \upsilon},\frac{\partial X}{\partial \upsilon}] - \psi^T D^2_{W,X} E.[\frac{\partial W}{\partial \upsilon},\frac{\partial X}{\partial \upsilon}] - \phi^T \frac{\partial L}{\partial x}\frac{\partial^2 x}{\partial \upsilon^2}$$

Explicit — Implicit CFD — Implicit deformation

Ludovic Martin PhD, 2010,
CANUM Award

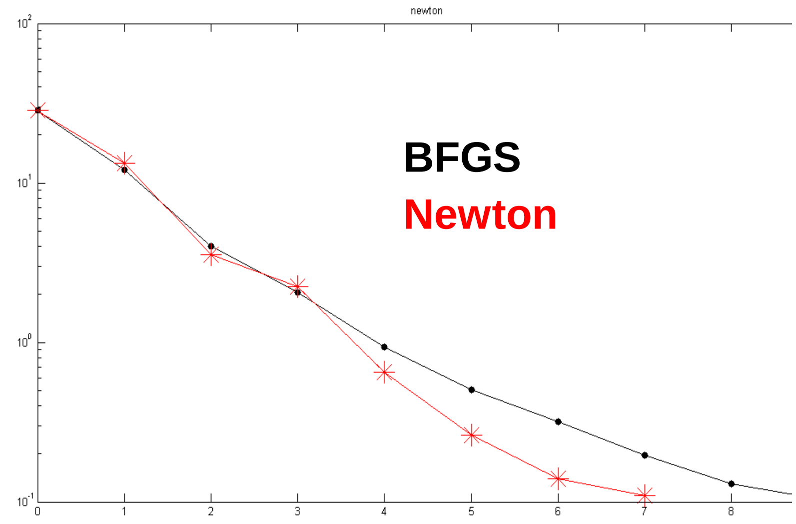
3D CFD Optimization using Newton

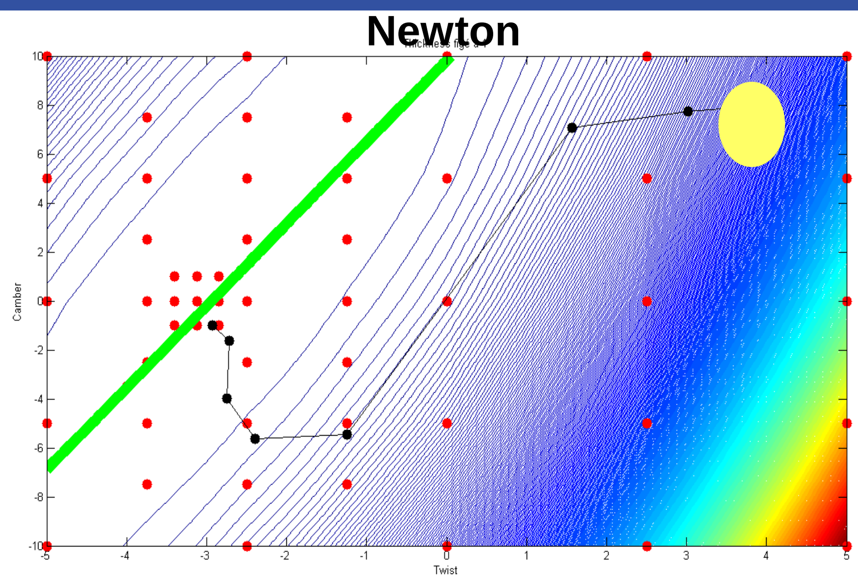


ONERA m6 wing
Mach = 0,84 , aoa= 3,06°

BFGS: cost = 20 (19 NF + 10 Ng)

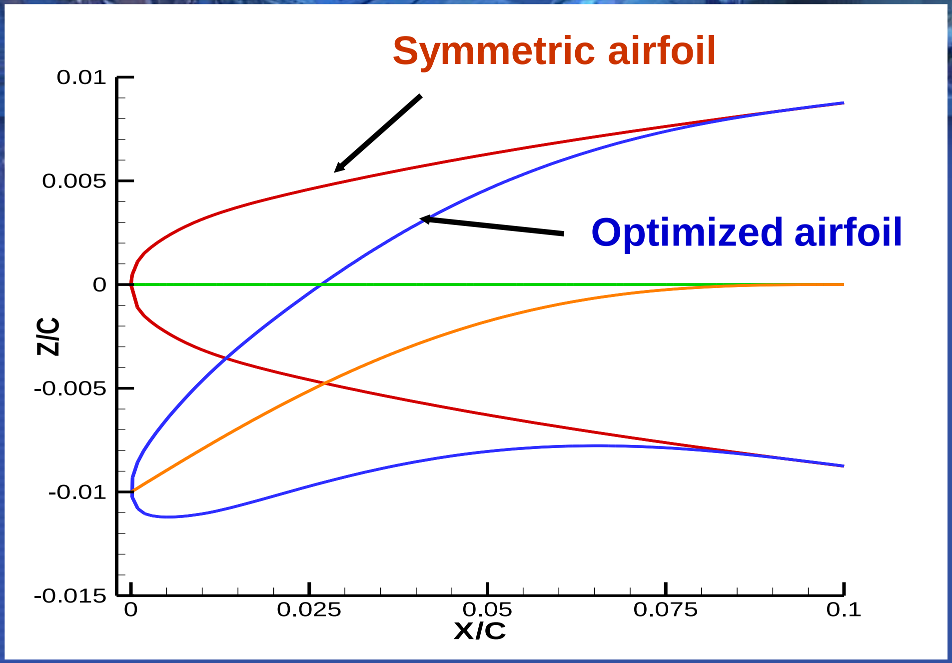
Newton: cost = 16 (15 NF + 8 Ng + 8 Nh)

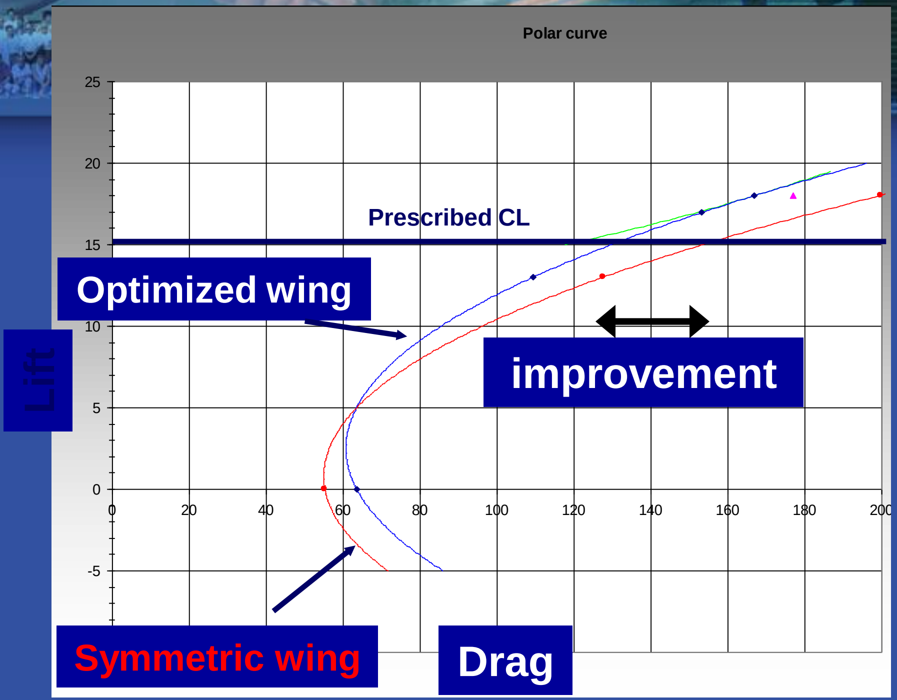


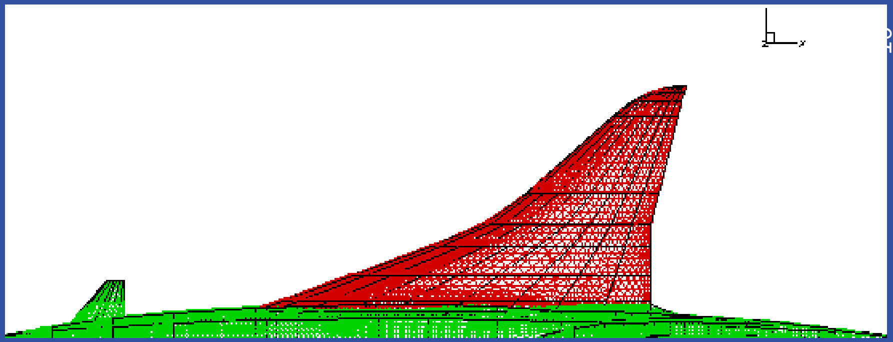


Wing twist and camber optimization

Supersonic cruise at Mach=1.6







9 control sections
4*9=36 design variables
36+1=37 optimization variables

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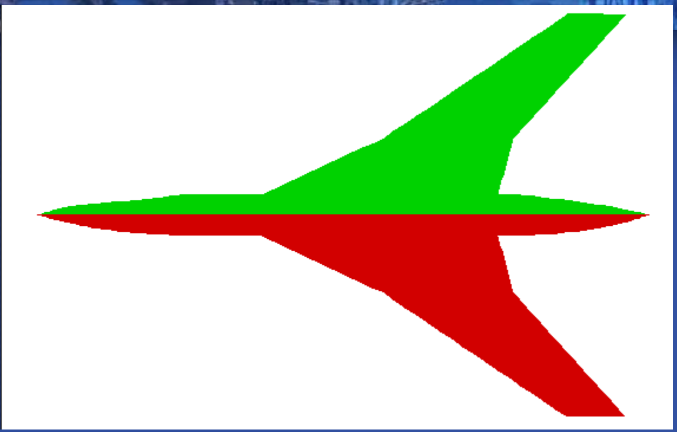
Sonic Boom minimisation process

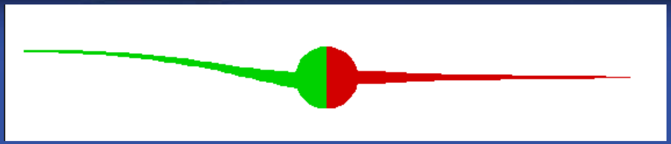
Shape before / after minimisation



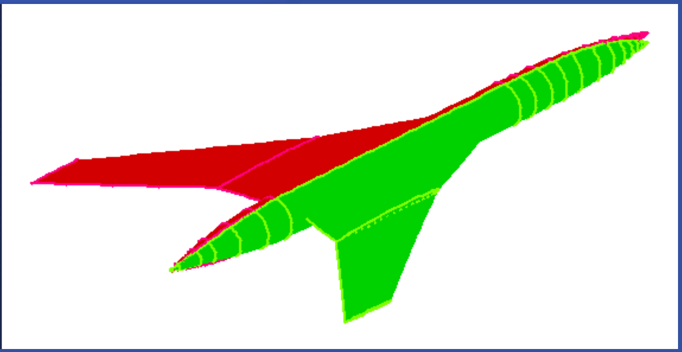
<u>67 optimization variables:</u>

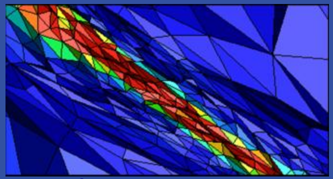
- Angle of attack (aoa)
- fuselage: scale, thickness, camber angle for 18 sections, 1 dihedral angle (nose)
- wing: twist angle, camber parameters for 3 sections, 2 dihedral angles (inner and outer wing)

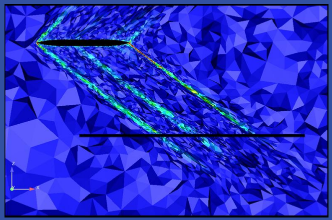
Wing dihedral

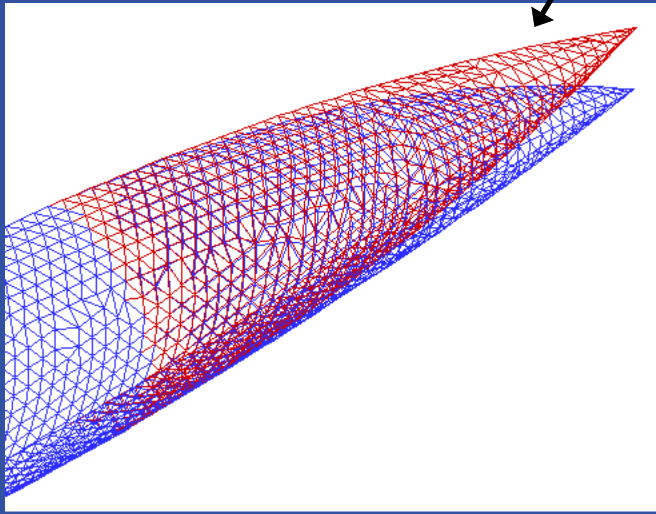


Nose camber

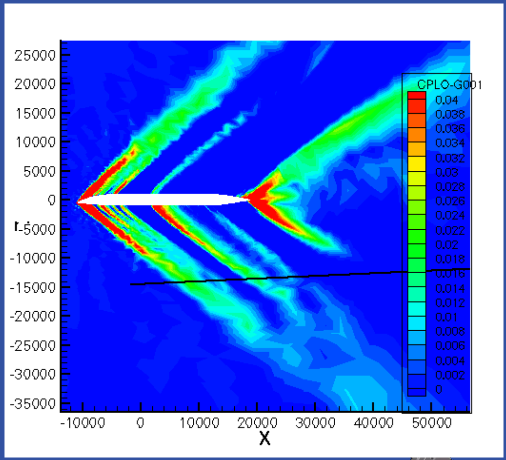






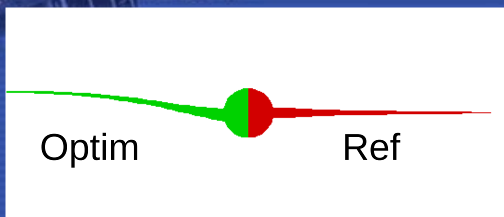


Extraction / propagation

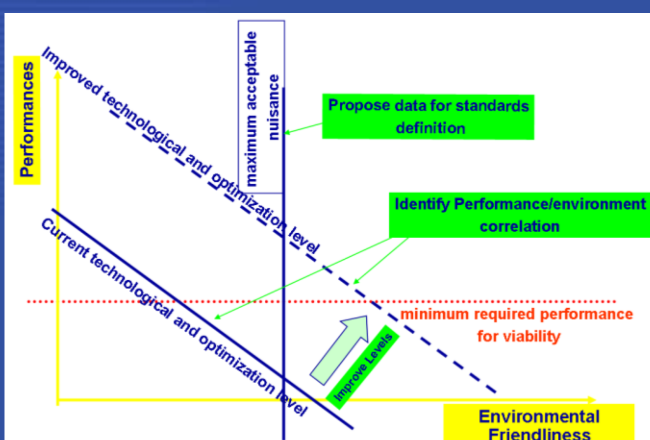


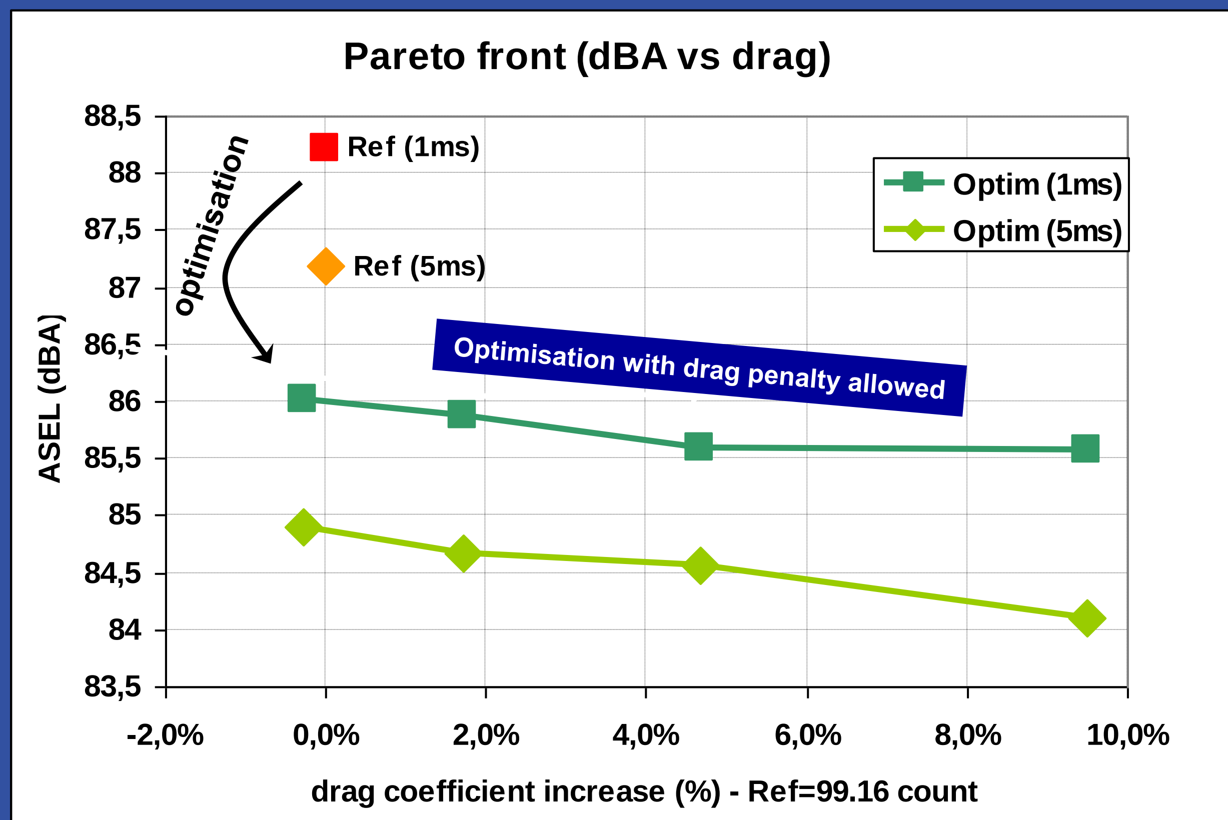
Same Sonic Boom optimization <u>drag increase allowed</u>

HISAC project (IP - 6th FP)



- The drag constraint has been relaxed at different levels in order to see if more noise reduction (dBA and dBC) could be achieved.
- 2 meteo conditions are considered => Rise time of the ground overpressure is either 1ms or 5 ms.

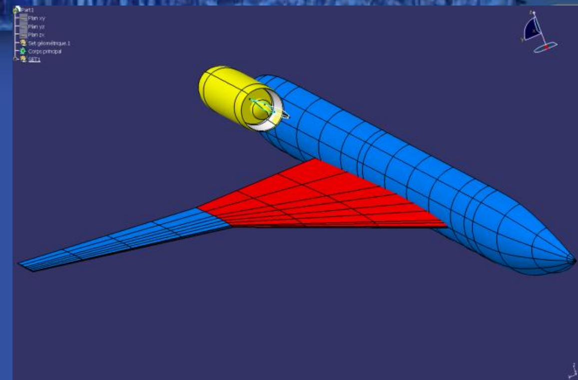




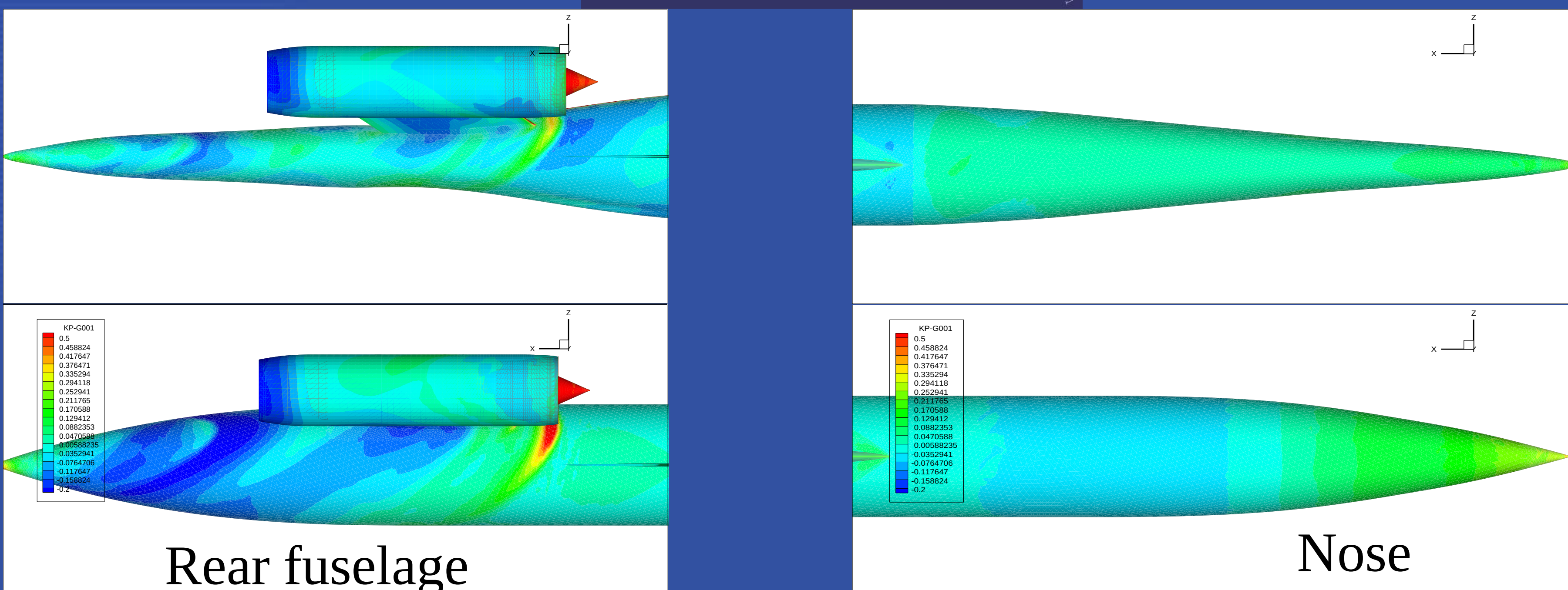
DASSAULT AVIATION

Engine integration optimization

HISAC project (IP - 6th FP)



Gain: 60 %
on zero-lift drag



Cp distribution

Optimization of High Lift configuration within European project DESIREH

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

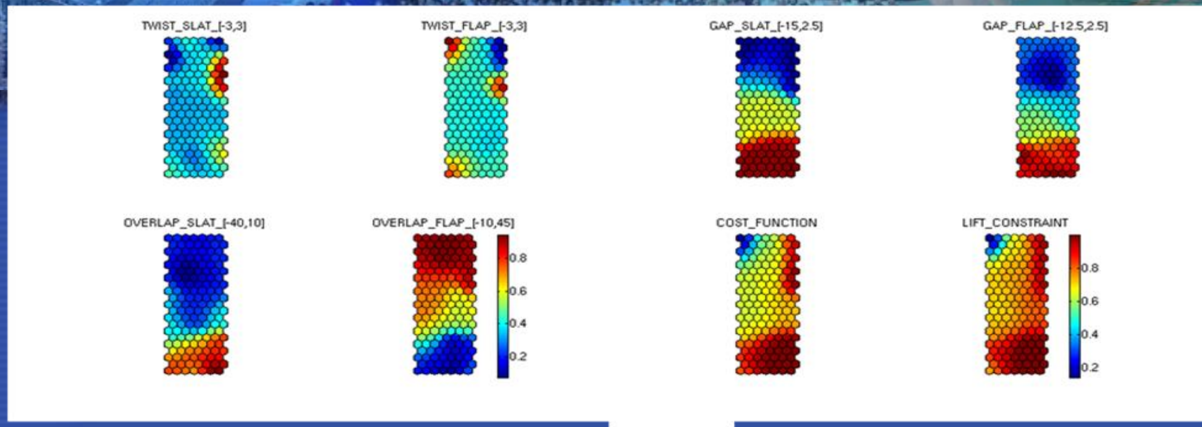
Presentation with kind permission of activities funded within Seventh Framework Programme
EC – Grant Agreement N° ACP8-GA-2009-233607

Steven Kleinveld

2.5D High Lift optimization

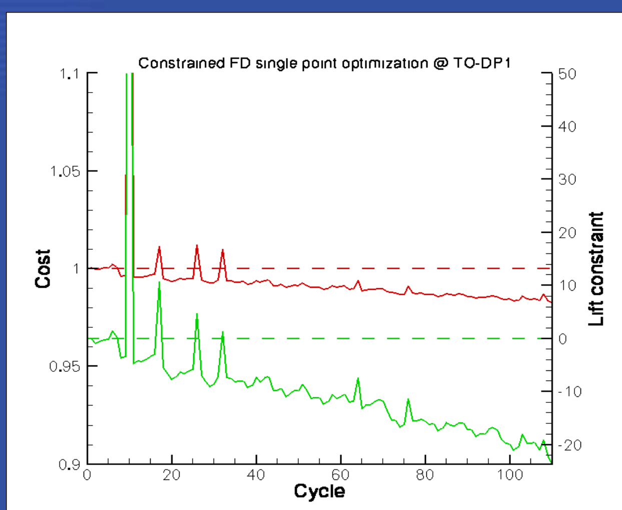
Use of various techniques to search for improved performance at take-off and landing

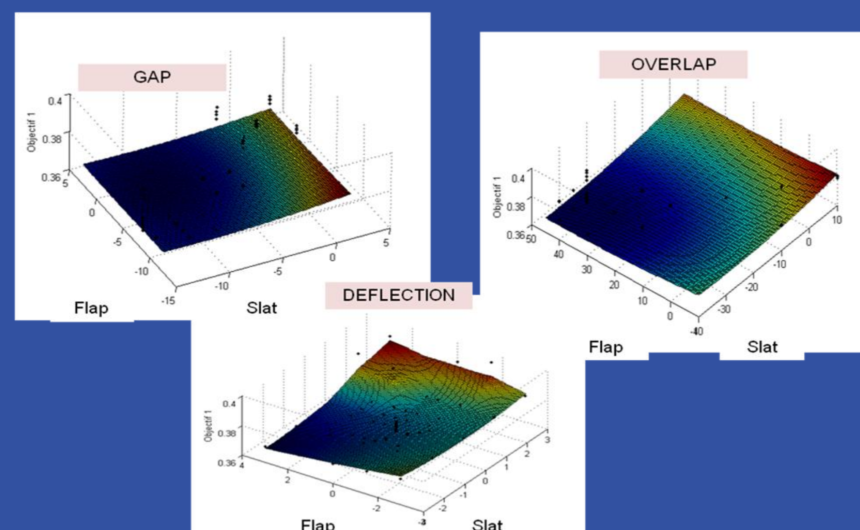
SOM



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

FD

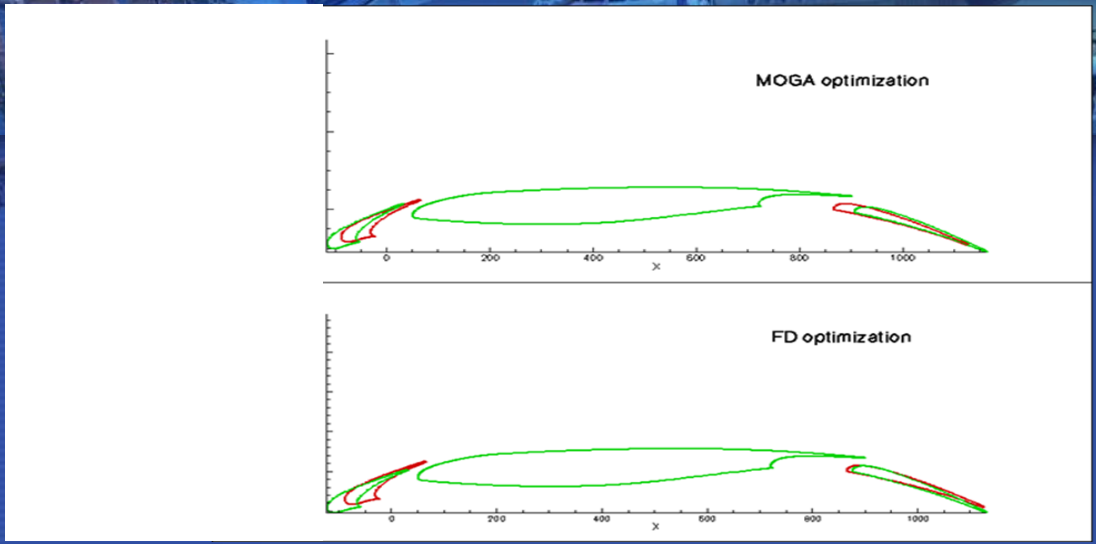




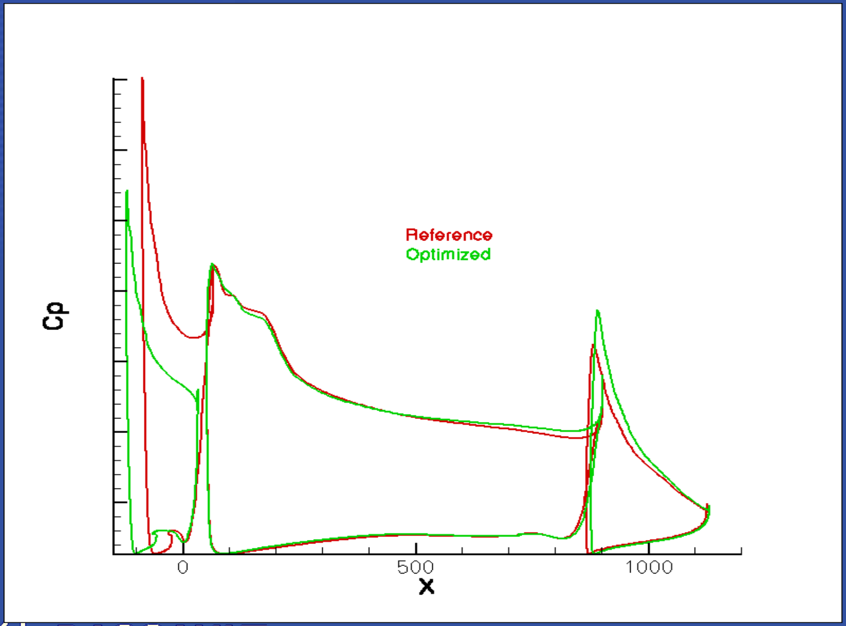
MOGA

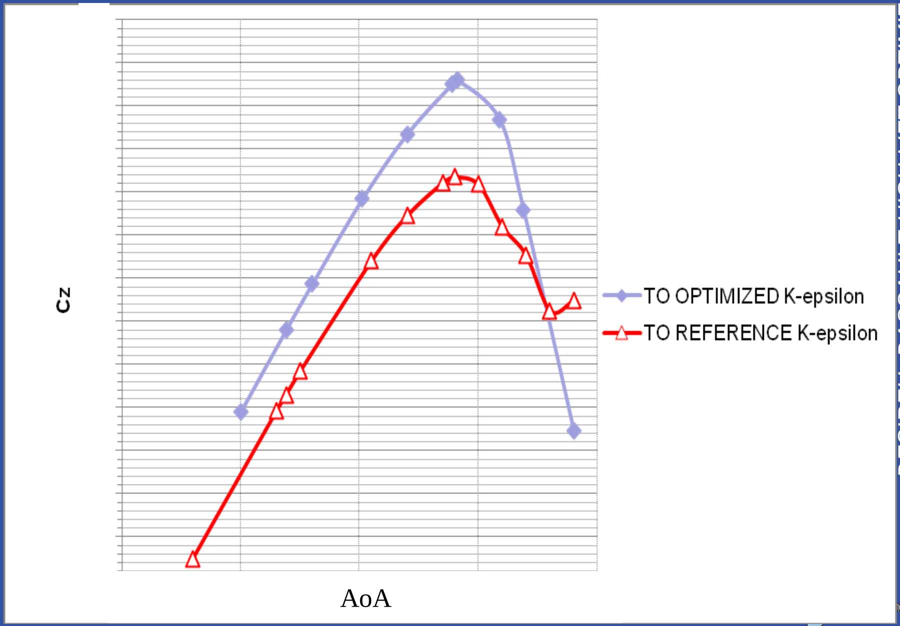
DESIREH- DASSAULT-HIGH LIFT OPTIMIZATION

2.5D High Lift optimization

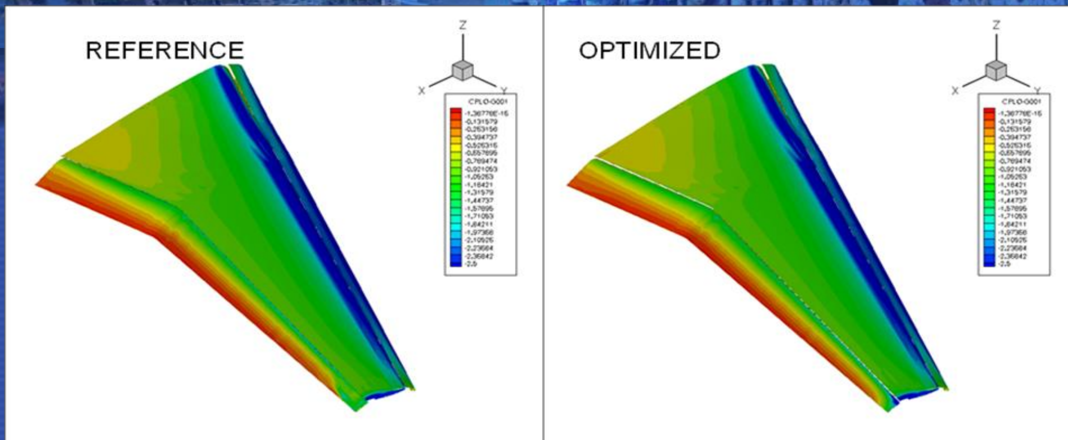


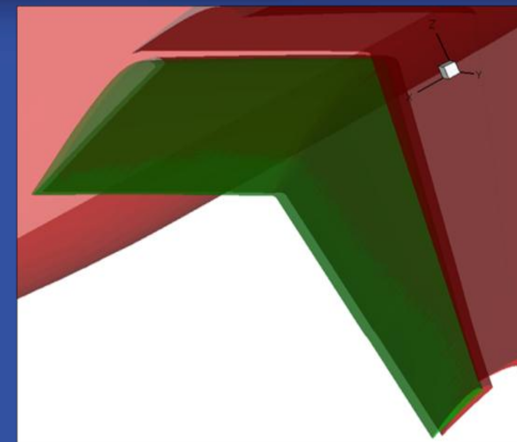
Example of performance improvement through optimization at Take-Off conditions for classical high lift configuration
using setting variables (gap,overlap,deflection angle)

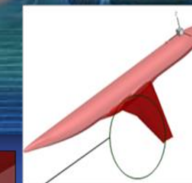




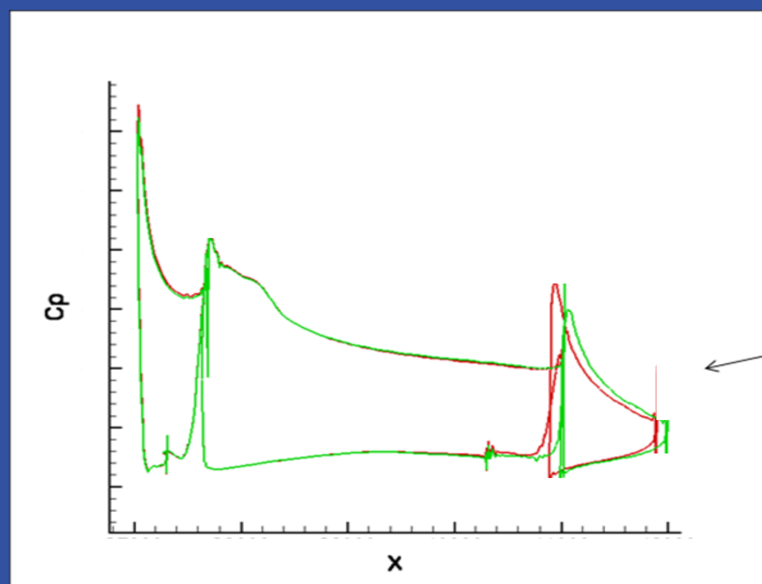
3D High Lift optimization

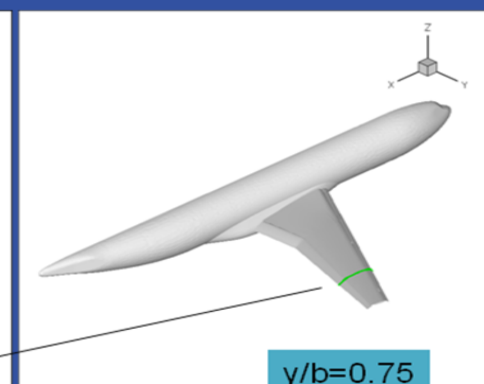






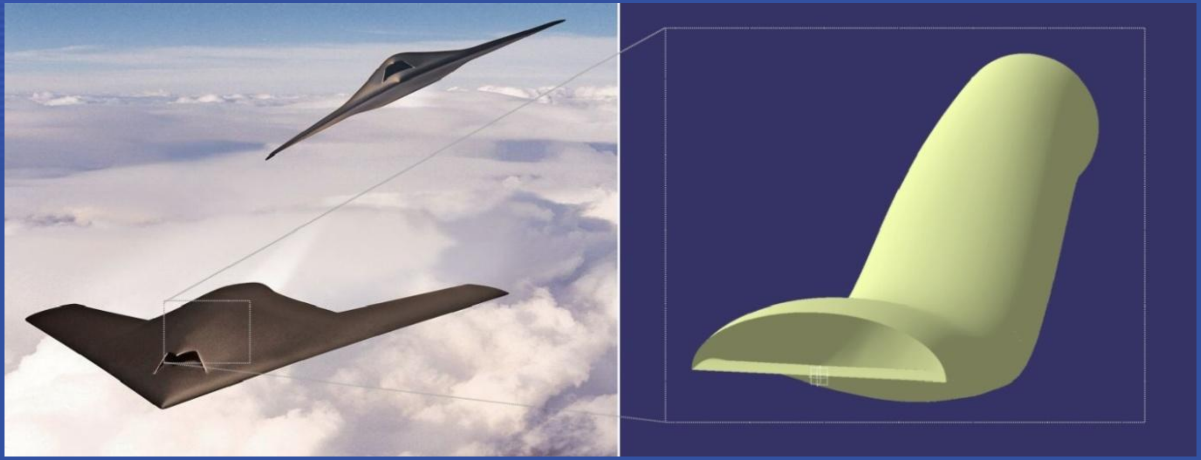
Example of flap position optimization at Take-Off conditions of 3D configuration taking into account variations of the intersection with fuselage





Control and optimization of separated flows

- PhD thesis J. Chetboun : Dassault Aviation / 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 vortex generators (VG).



Topological derivative and parametric optimization

- Vortex generators modelled by source term added to NS equations.
- Creation of a new VG : topological derivative.
- Sizing : parametric optimization.
- State equation and cost function :

$$E(V, \chi f(V, l)) \qquad J(\chi, l) = j(V(\chi, l))$$

- Adjoint state equation :

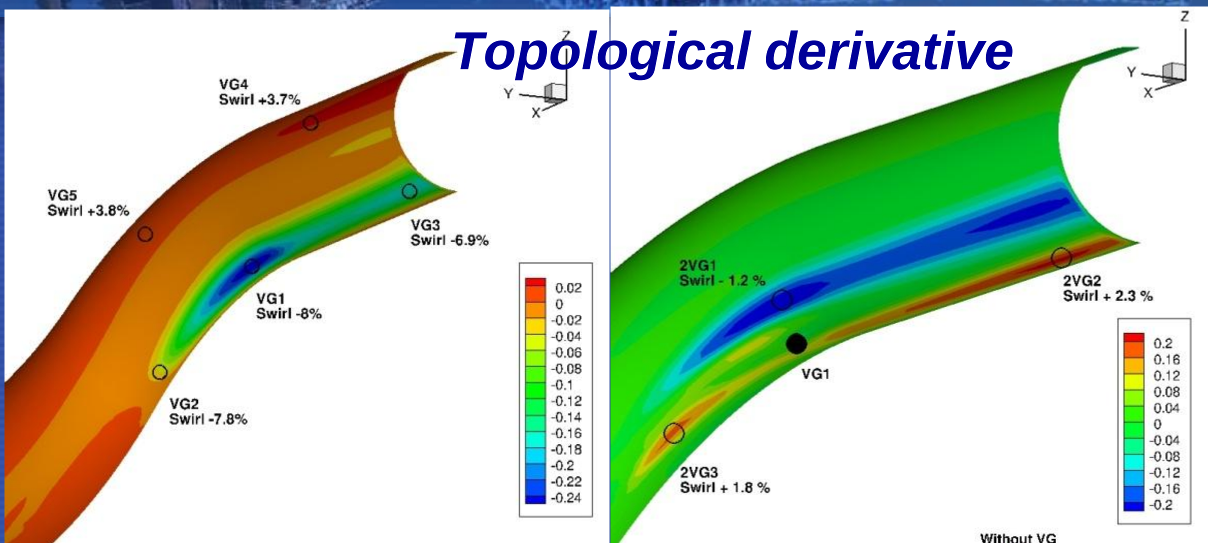
$$P^T \left(\frac{\partial E}{\partial V} + \frac{\partial E}{\partial f} \frac{\partial \chi f}{\partial V} \right) (V, \chi f(V, l)) = \frac{dj}{dV}(V)$$

- Topological and parametric derivatives :

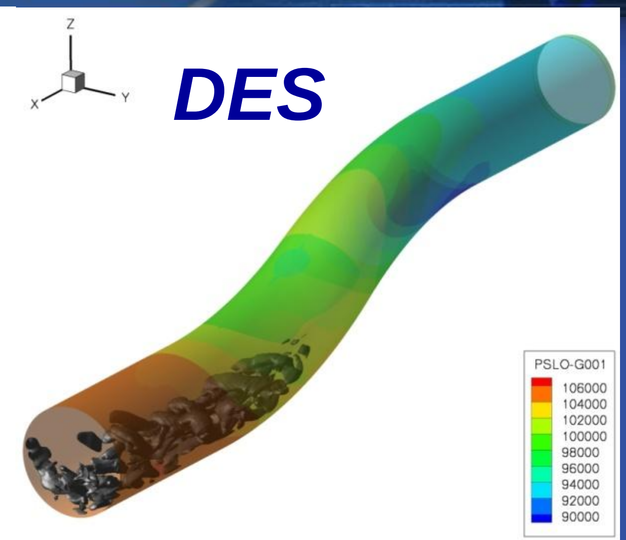
$$g = P^T \chi^\delta f(V, l) \qquad \frac{\partial J}{\partial l} = -P^T \left(\frac{\partial E}{\partial f} \frac{\partial \chi f}{\partial l} \right) (V, \chi f(V, l))$$

Applications : S-duct, U-duct, unsteady computations

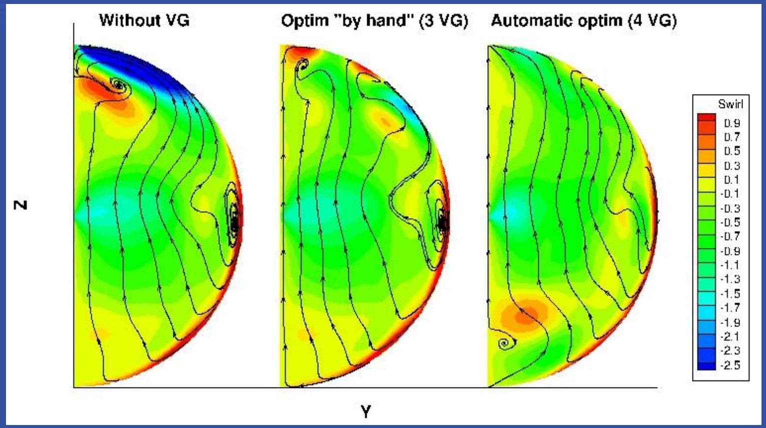
Topological derivative

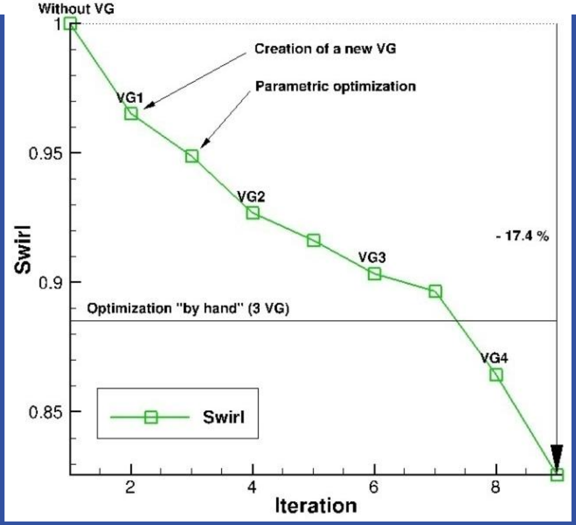


DES



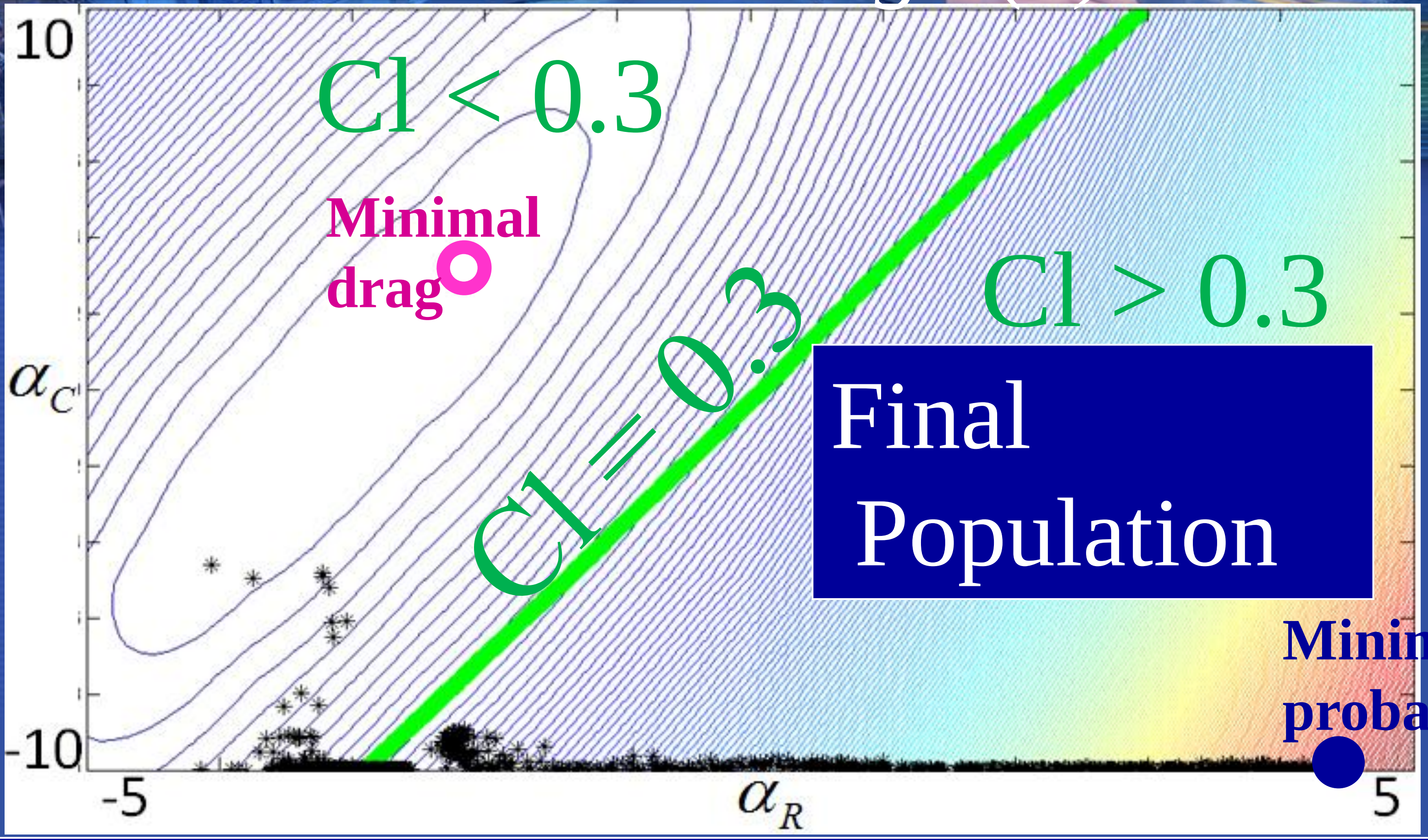
Swirl





Complete optimization

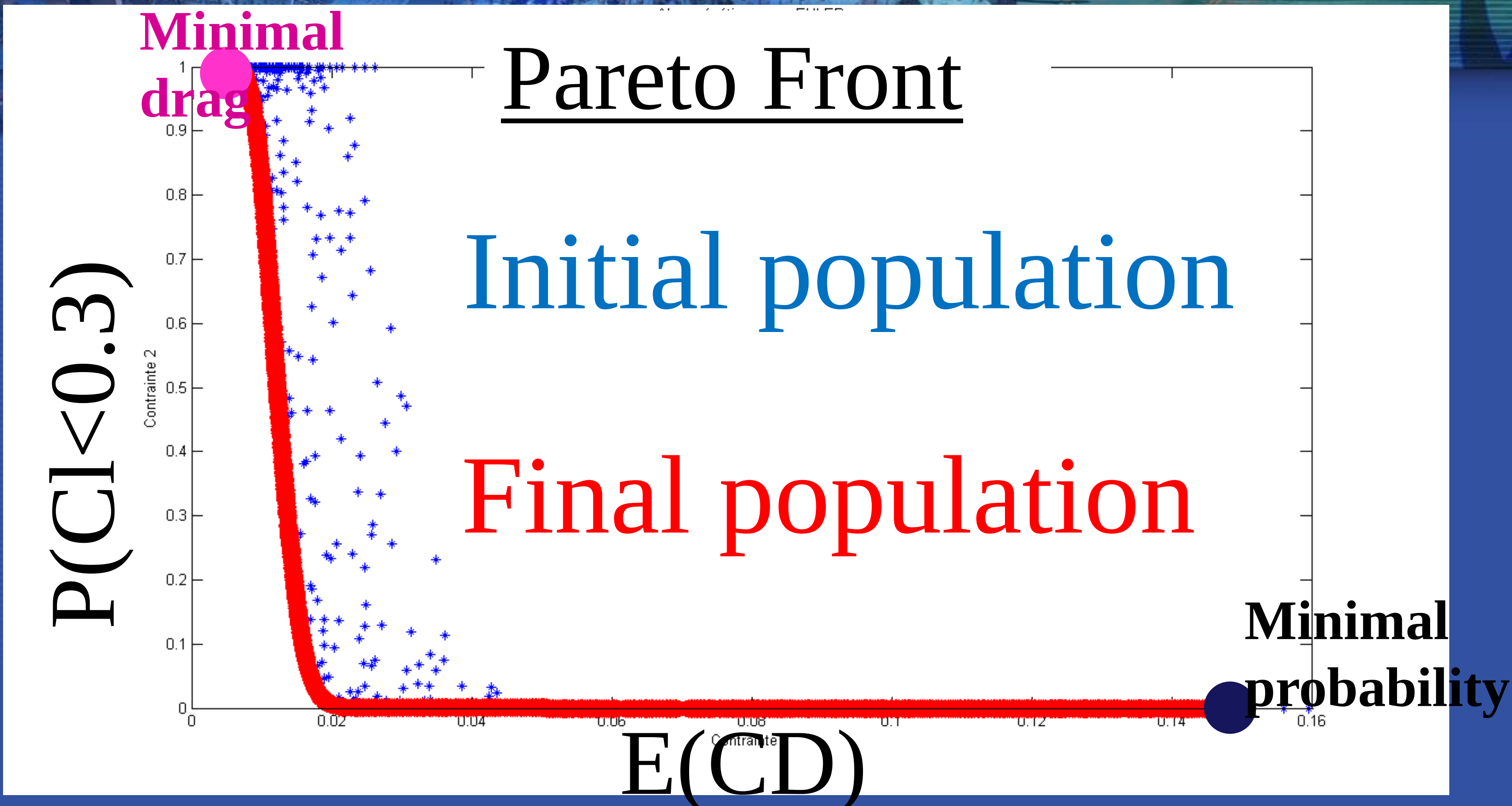
Robust Design (1)



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)

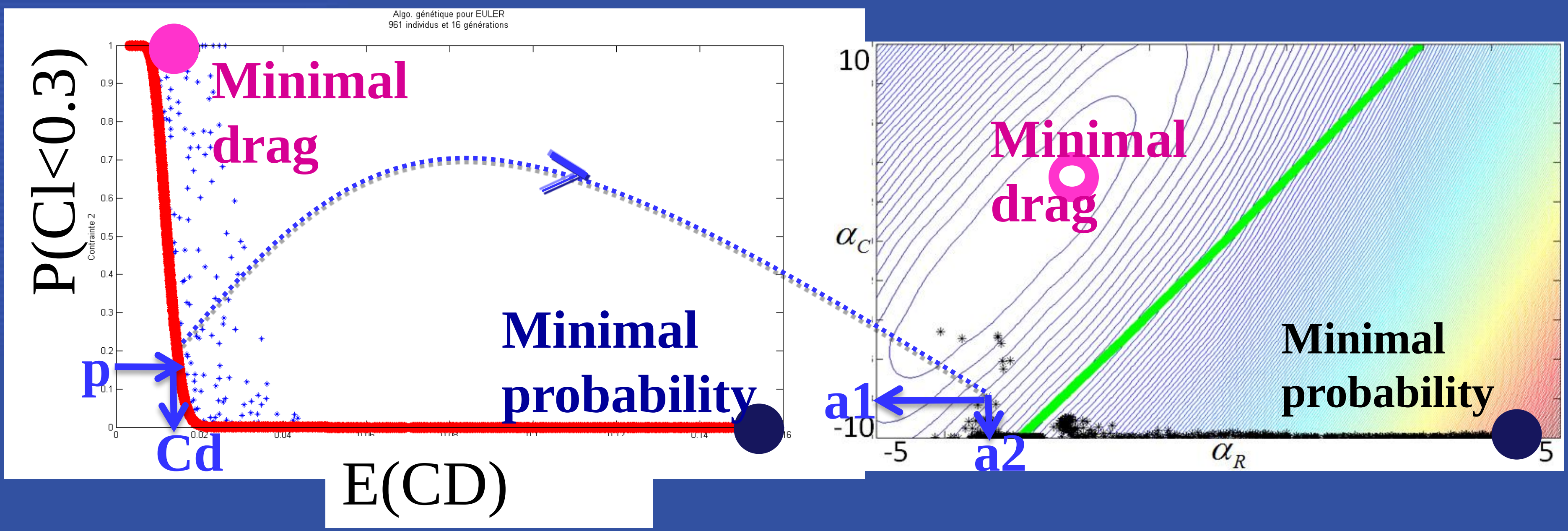


Robust Design (3)

<u>Decision:</u> 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)

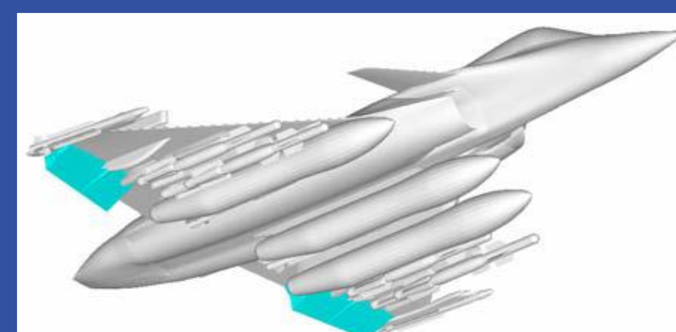


Conclusion

- Aerodynamic Shape Design Optimization based on CAD (geometric constraints, …) and Adjoint
- Euler, RANS, cruise, TO, Unsteady, turbulence and transition modelling
- Bidisciplinary Optimization (Mass, Flutter, RCS, …)
- Robust Design, Uncertainties

Falcon ++

UCAV ++



Aircraft Fighter ++

DASSAULT AVIATION

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Q & A