Combining Game Strategies and Evolutionary Algorithms for CAD Parameterisation and Multi-Point Optimisation of Complex Aeronautic Systems

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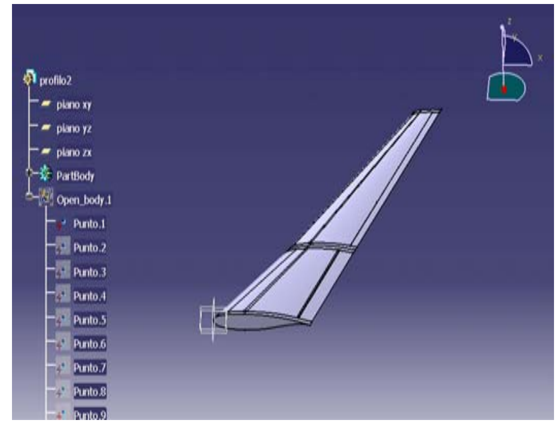
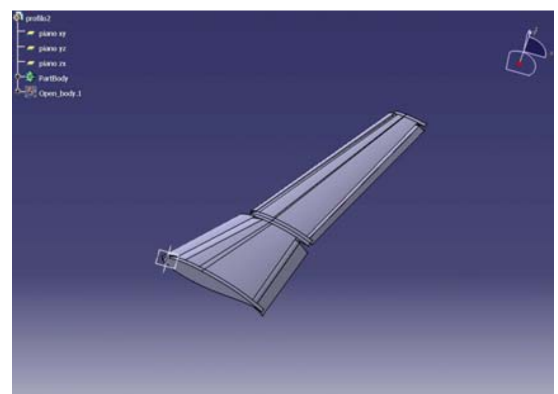
Definition of the problem: multi-point 3D wing design

- Transonic point:
  - minimise **Drag**
  - angle of attack: 2°
  - Mach number: 0.7
  - lift and max thickness constrained to original



- Subsonic point:
  - maximise **Efficiency**
  - angle of attack: 17.12°
  - Mach number: 0.12

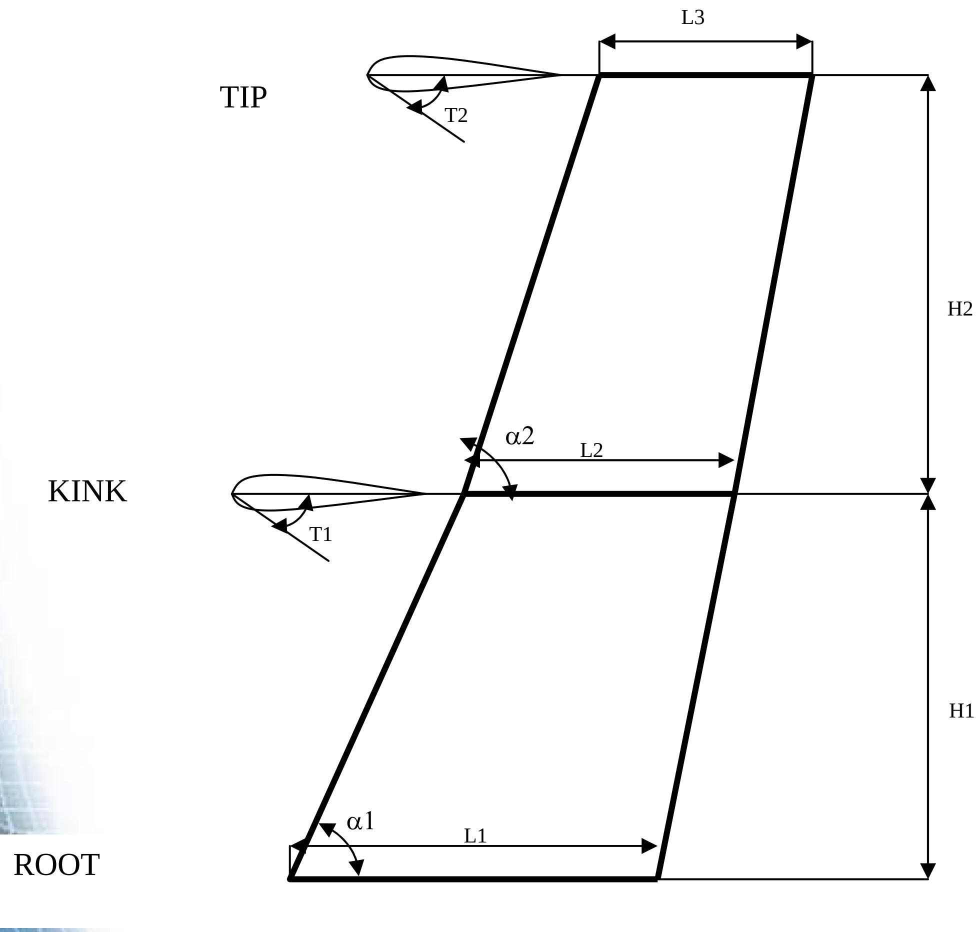


Parameterisation

- The 3D wing parametric model is defined inside CATIA V5:

- **1) 9** geometric variables parameterise the planform
- **2) 30** variables parameterise the shape of 3 main sections
- **3) 26** variables parameterise internal shape and position of the flaps

Parameterisation

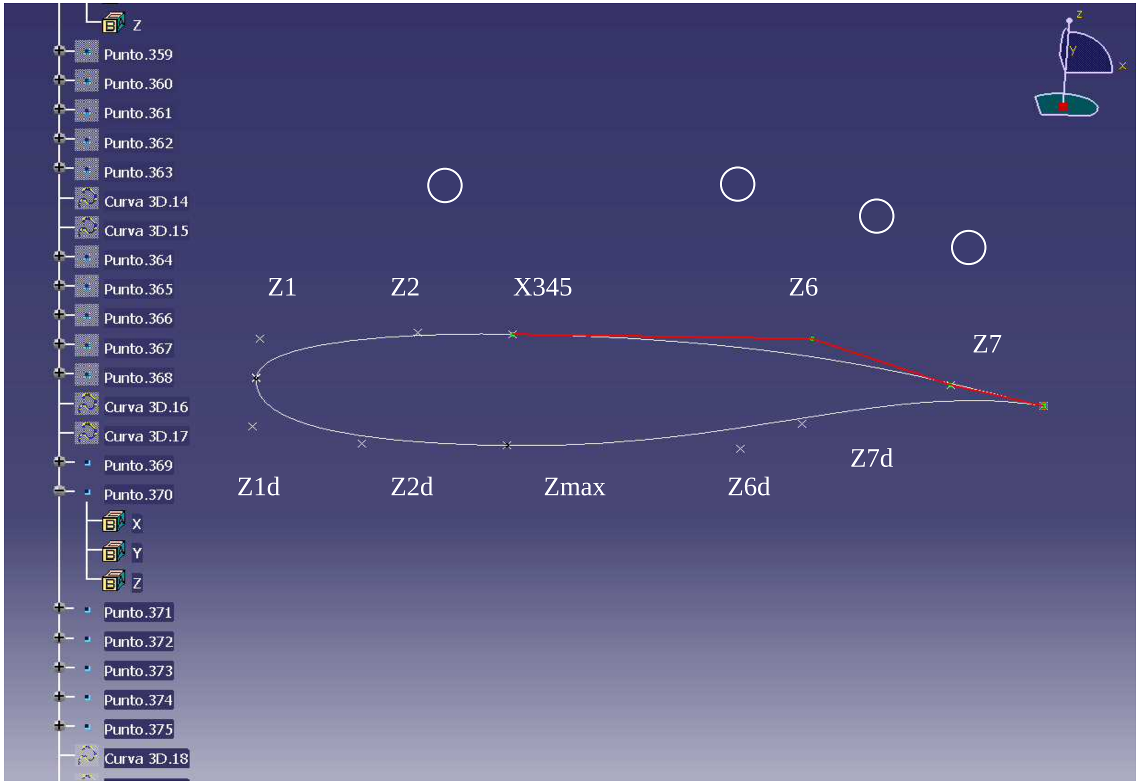


1) PLANFORM PARAMETERISATION

- L1: length of root section (500mm)
- L2 length of kink section (300mm)
- L3 length of tip section (150mm)
- H1 root-kink distance (500mm)
- H2 kink-tip distance (1000mm)
- α1 root angle (55°)
- α2 kink angle (60°)
- t1 twist angle of kink section (0°)
- t2 twist angle of tip section (0°)

These parameters were kept constant

Parameterisation

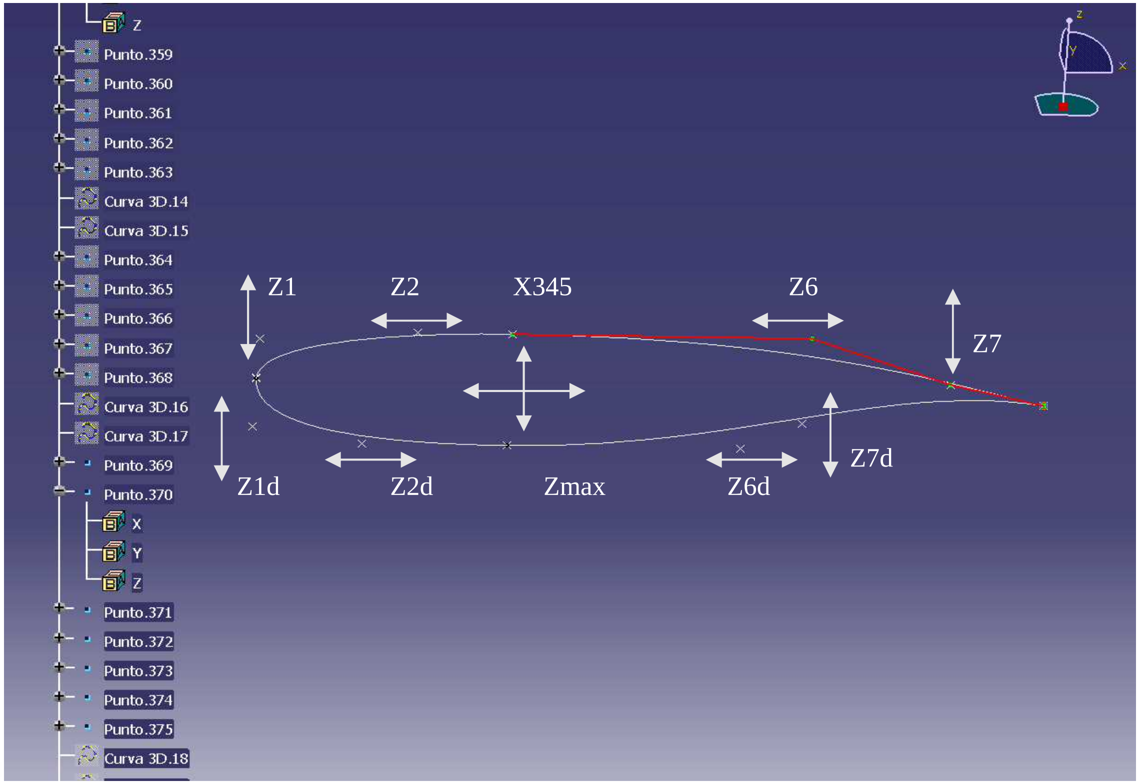


2) SMOOTH SHAPE PARAMETERISATION

3 main sections (root,kink,tip)

4 NURBS curves (of 4 control points) for each section

Parameterisation



2) SMOOTH SHAPE PARAMETERISATION

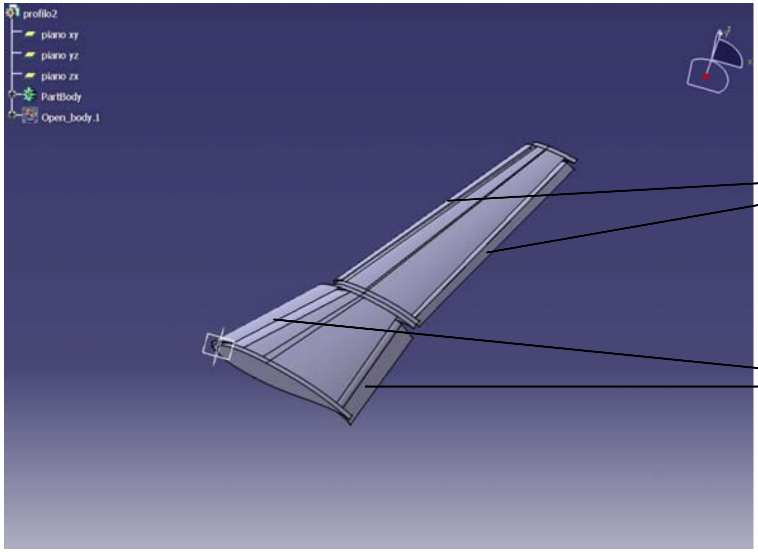
3 main sections (root,kink,tip)

4 NURBS curves (of 4 control points) for each section

10 geometric variables for each section = **30 total sections shape variables**

Parameterisation

3) DEPLOYED POINT PARAMETERISATION

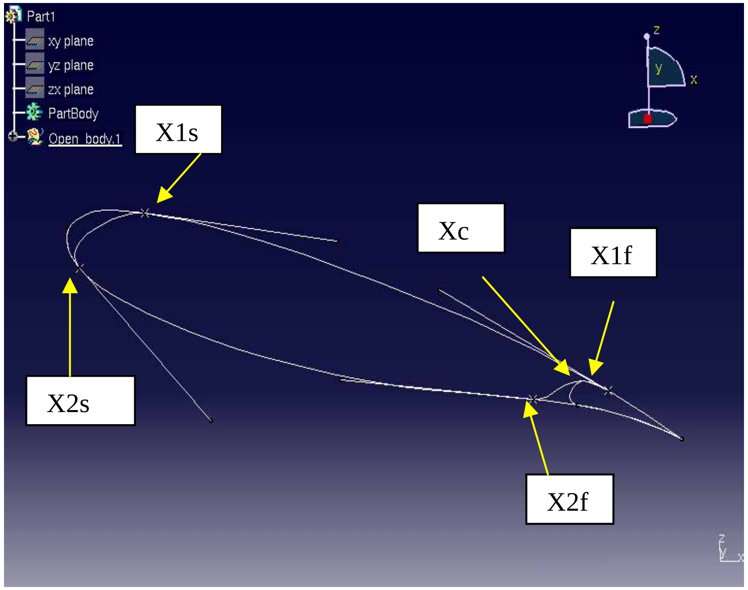


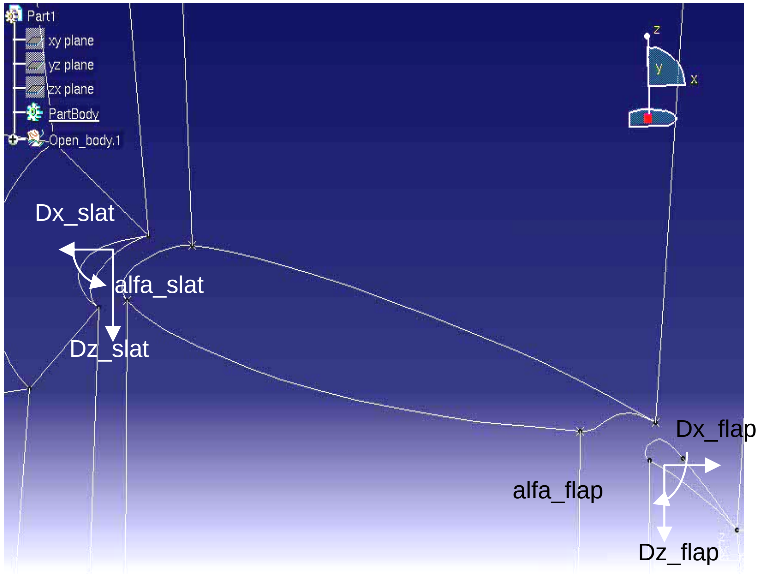
2 couples of slats and flaps (**2** sets of **13** variables)

Each set corresponds to: **7** internal side shape variables
6 position variables

Parameterisation

3) DEPLOYED POINT PARAMETERISATION

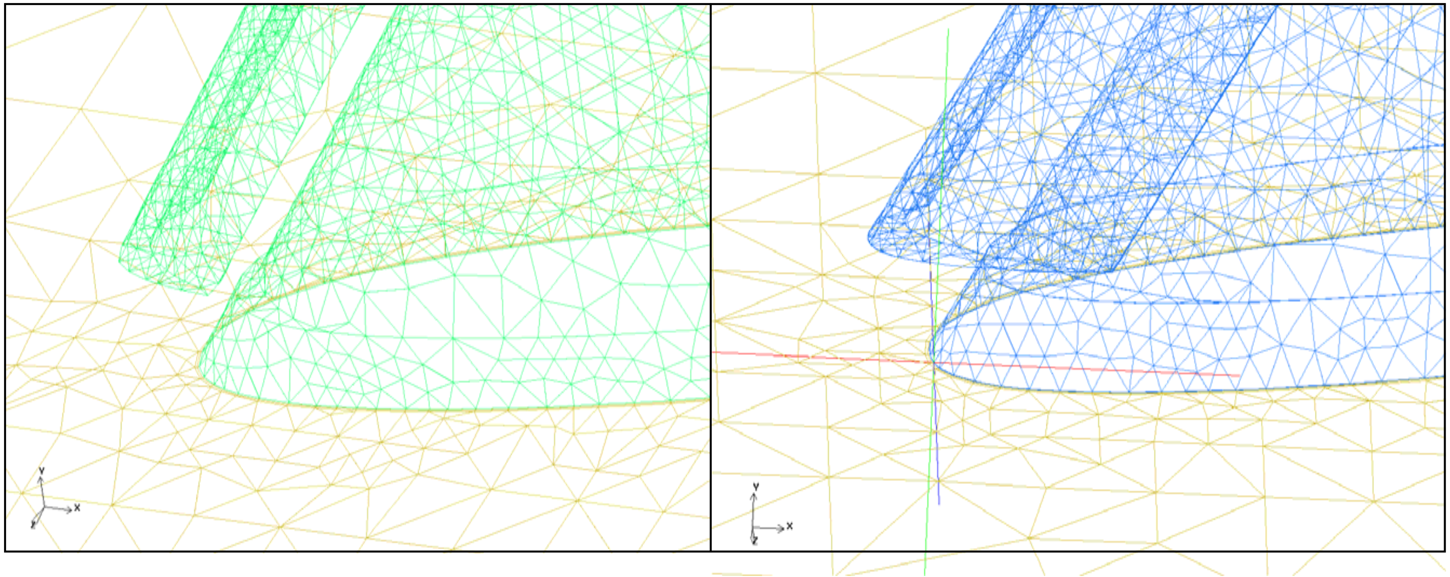




internal sides of slat and flap are defined by **conic curves** (**7** var.)

position of slat and flap is defined by **6** geometric variables

Mesh generation



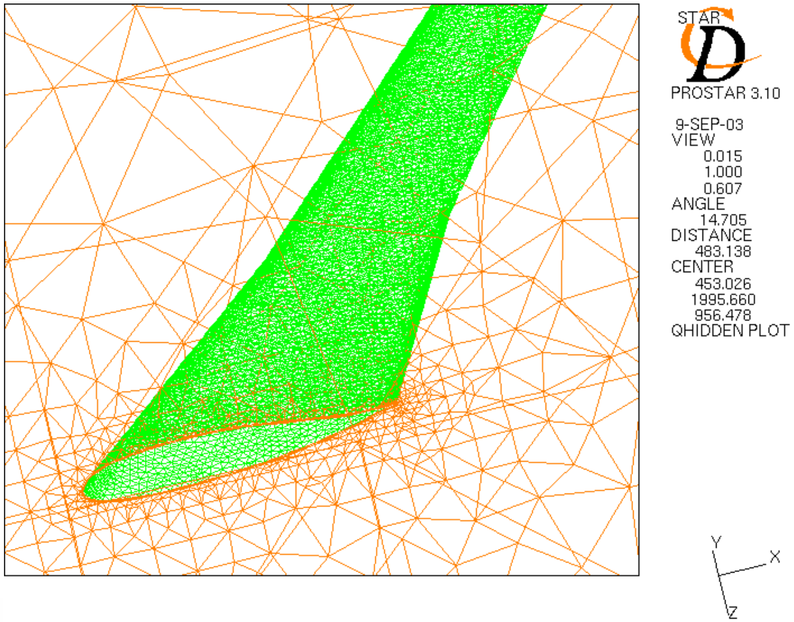
Catia → model file → ICEM → mesh file

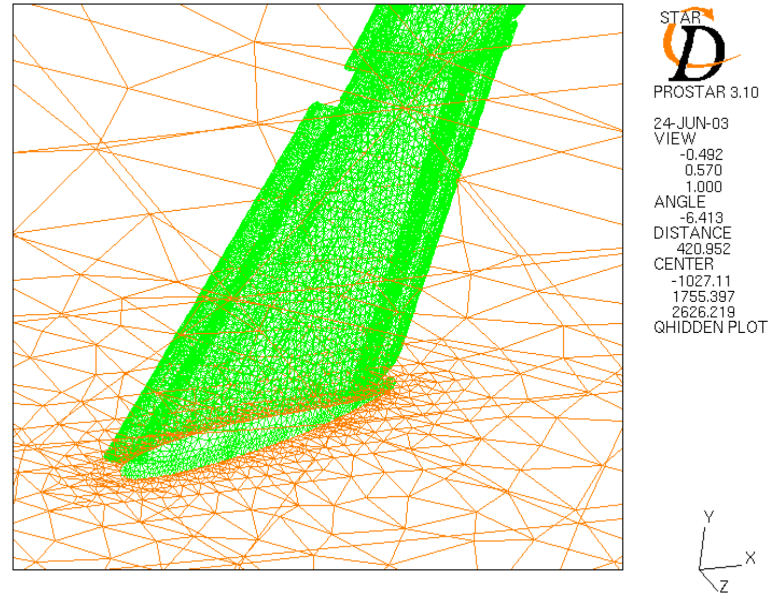
Unstructured mesh: **tetrahedral** cells (about 500,000), 3 **prism** layers

-Mesh conserves topology and accuracy at geometry variations

-Mesh is automatically updated for each configuration

Flow simulation





ICEM → mesh file → STARCD → fitness values

- y^+ values are regular (30-150)
- each simulation (1 mission point for 1 configuration) requires about 2hs

Optimisation: Game Theory

- In a problem of minimisation of two functions $f_A(x,y)$ and $f_B(x,y)$ with $(x,y) \in A \times B$:

- $A \times B$ is defined as space of the rational strategies
- A is considered as **Player A**, he can play strategies x
- B is considered as **Player B**, he can play strategies y

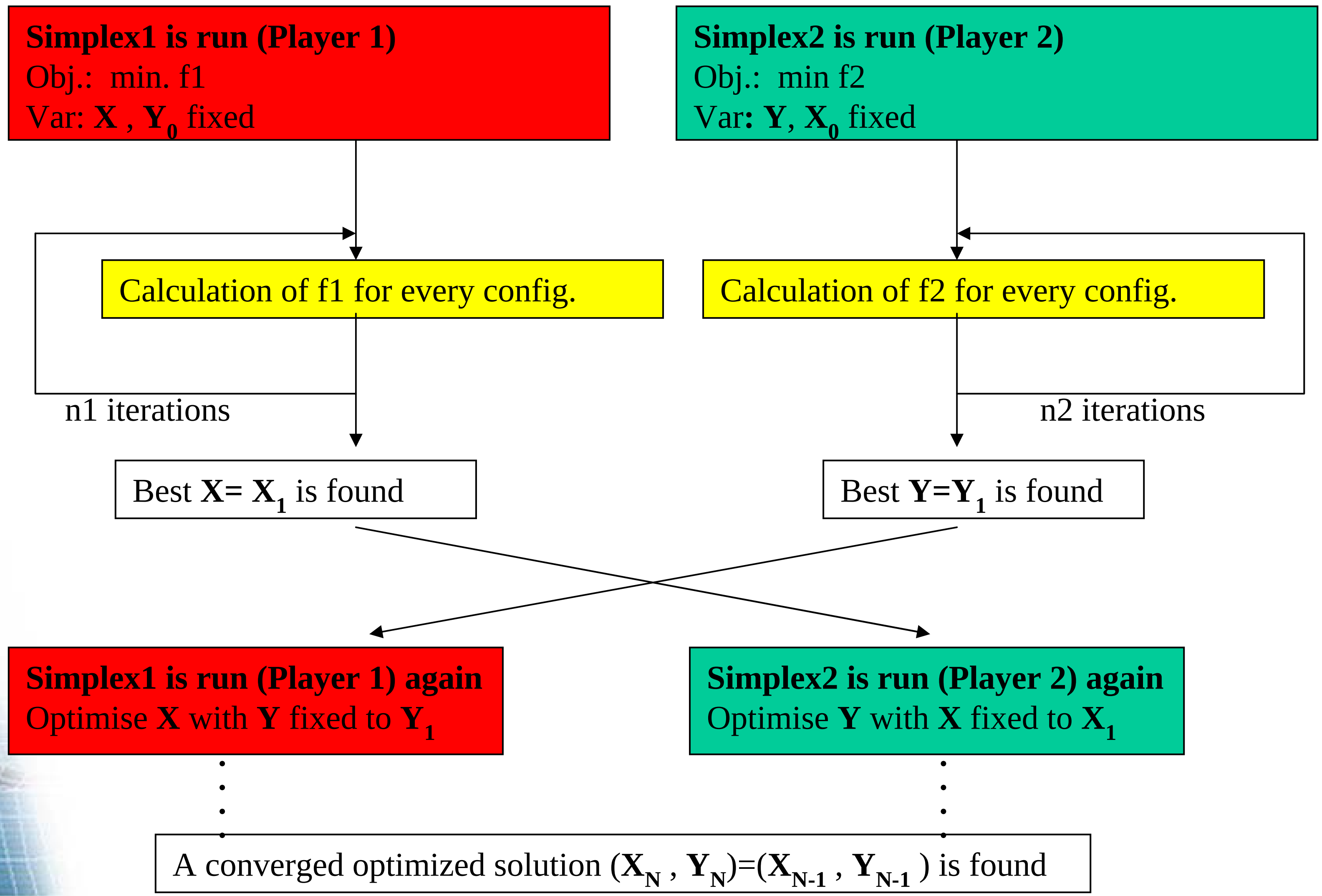
- In a **Competitve Game**:
- Player A have to minimise function $f_A(x,y)$
- Player B have to minimise function $f_B(x,y)$

Optimisation: Game Theory

- The strategy $(x^*,y^*) \in A \times B$ is defined as a **Nash equilibrium** if and only if:

$$\begin{cases} f_A\left(x^*, y^*\right) = \inf\ f_A\left(x, y^*\right) & x \in A \\ f_B\left(x^*, y^*\right) = \inf\ f_B\left(x^*, y\right) & y \in B \end{cases}$$

Optimisation: Nash/Simplex algorithm



Optimisation: Nash/Simplex algorithm

Player 1:

-the variables **x** are the 30 smooth sections shape ones

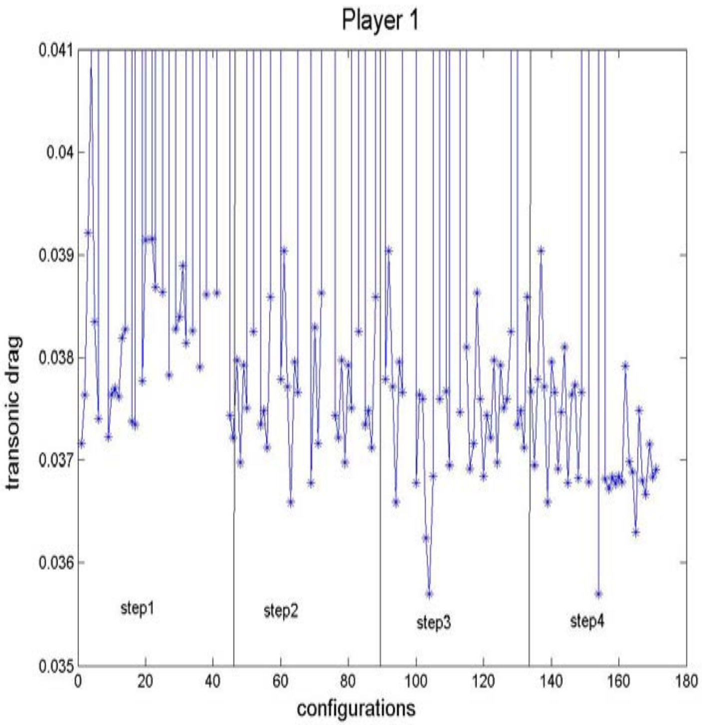
-the function **f1** is the transonic point drag to minimise

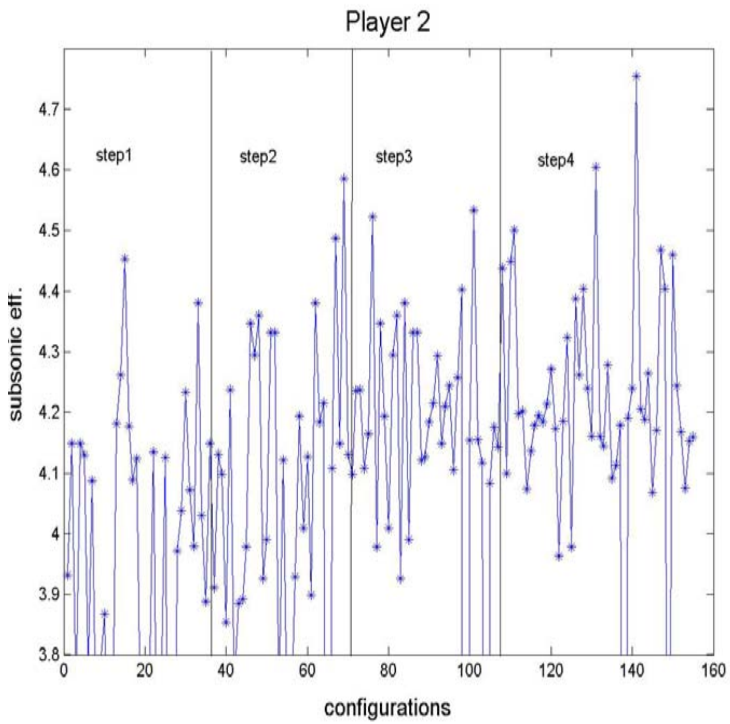
Player 2:

-the variables **y** are the 26 internal shape and position ones

-the function **f2** is the subsonic point efficiency to maximise

Optimisation results



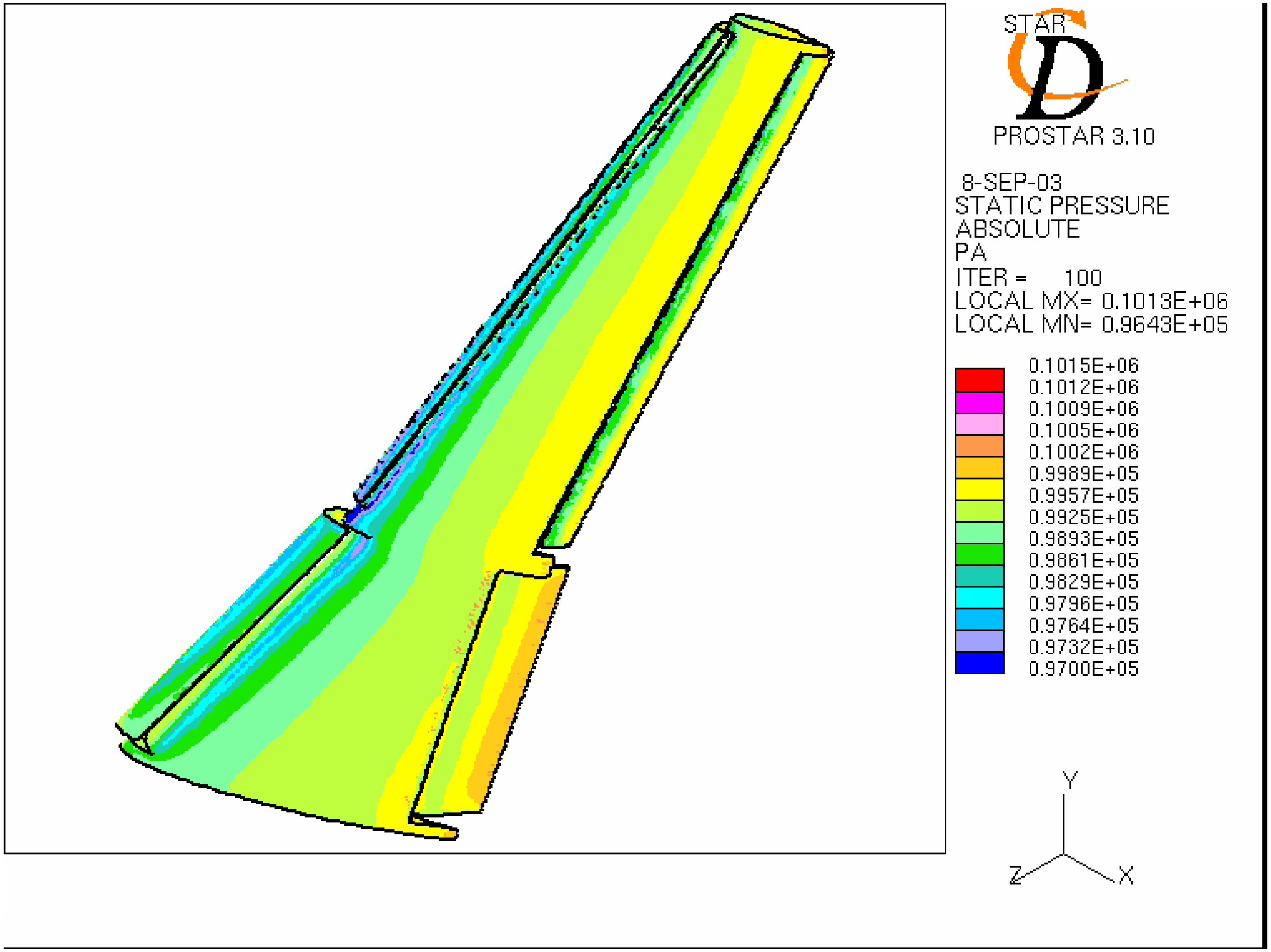


Player 1: 4 steps of 46 Simplex iterations

Player 2: 4 steps of 37 Simplex iterations

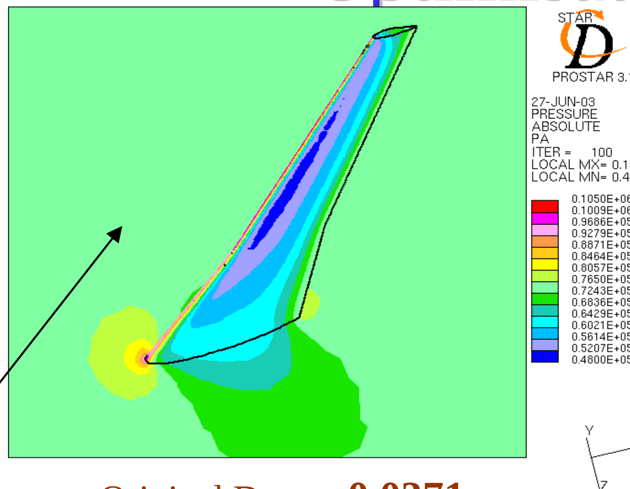
Total of about **350** simulations

Optimisation results

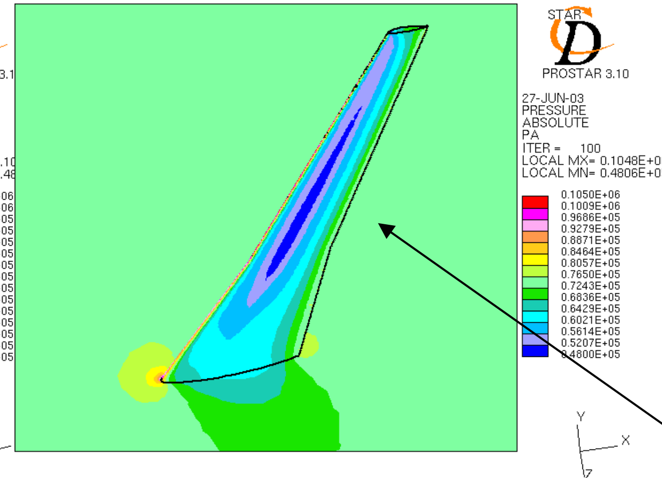


Optimisation results

Original config.

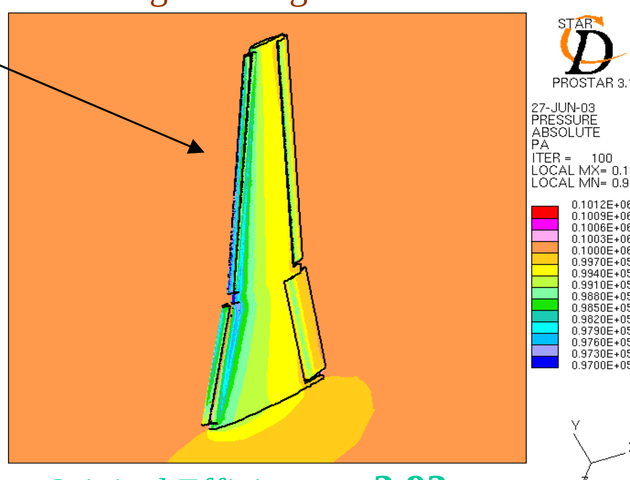


Original Drag = **0.0371**

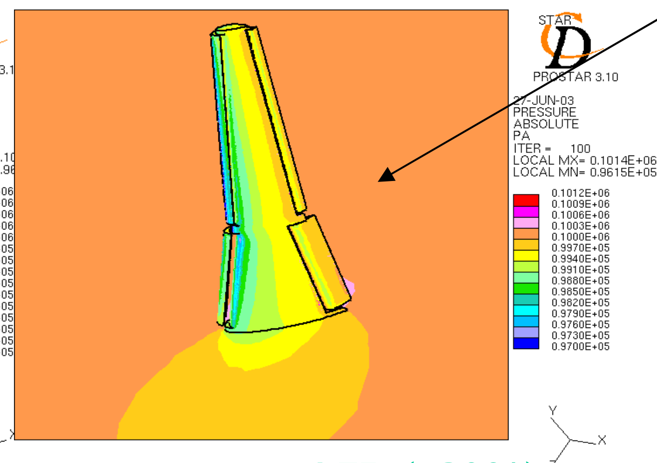


Best Drag = **0.0357 (-4%)**

Best config.

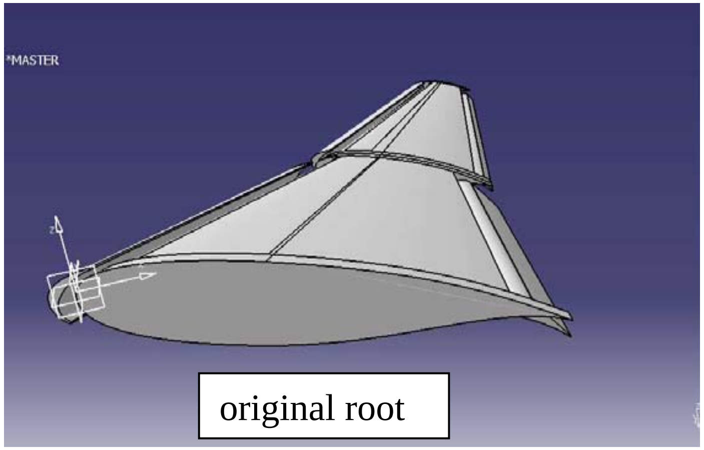


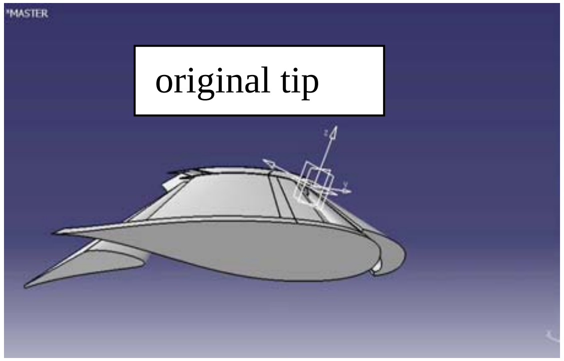
Original Efficiency = **3.93**

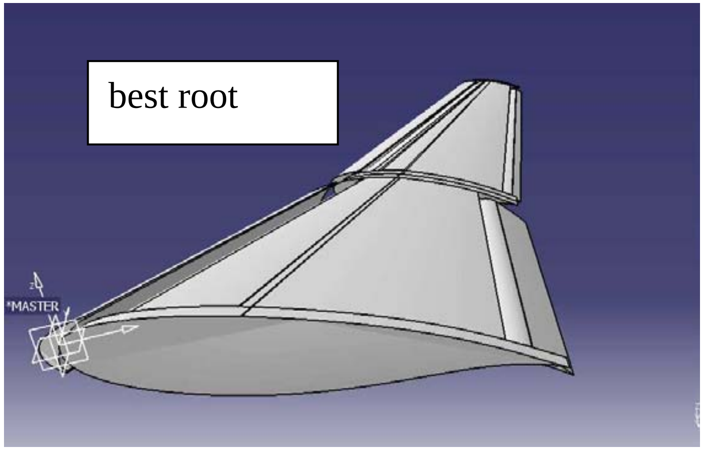


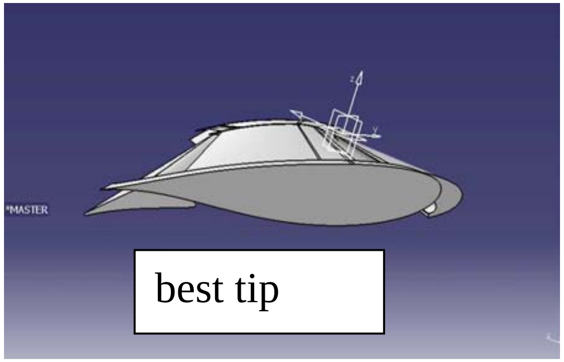
Best Efficiency = **4.75 (+30%)**

Optimisation results









Conclusions

ADVANTAGES OF CAD PARAMETERISATION

- any parametric CAD model can be integrated in the optimisation loop
- CAD tools allows the definition and parameterisation of complex design (like the multi-point working wing)

EFFICIENCY OF GAME THEORY COMBINED WITH GA

- Nash/Simplex algorithm proved its efficiency if designer need a unique solution to be obtained by few simulations

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