Innovative design with bi-level topology optimization

A. Remouchamps, M. Bruyneel, SAMTECH Liège, Belgium

C. Fleury, University of Liège, Belgium

S. Grihon, Airbus Toulouse

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Outline

- TOPOL software for topology optimization
- Original design of Airbus pylons
- Formulation of a bi-level optimization including TOPOL
- Application
- Conclusions

TOPOL software for topology optimization

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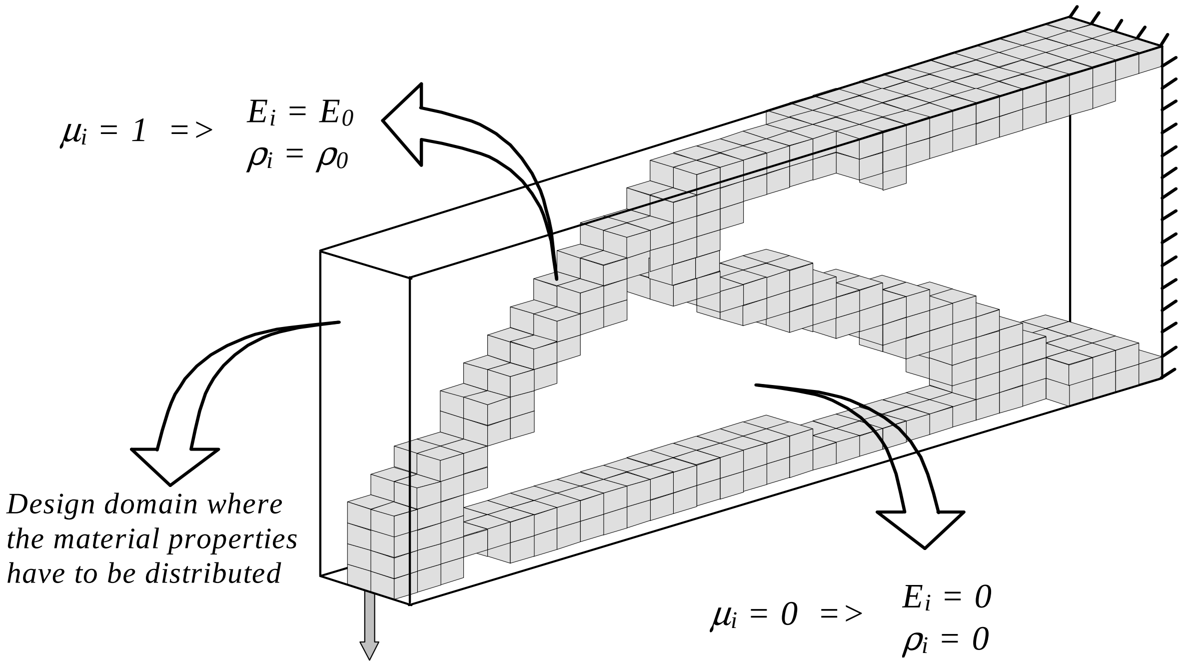
Classical formulation: maximize stiffness of the structure for a given volume fraction of material required at solution.



$\mu_i =$ design variable associated to each finite element ***i*** (**pseudo-density**)

- $\mu_i \approx 0$ Void at the solution in finite element *i*
- $\mu_i = 1$ Material at the solution in finite element *i*

TOPOL software for topology optimization

Classical formulation: maximize stiffness of the structure for a given volume fraction of material required at solution.

For the linear case:

$$\max_{\boldsymbol{\mu}} \min_{k=1,\ldots,nf} \omega_k \quad \text{with} \quad \left(\mathbf{K} - \omega_k^2 \mathbf{M}\right)\mathbf{q}_k = 0 \qquad \textit{Modal analysis}$$

$$\min_{\boldsymbol{\mu}} \max_{l=1,\ldots,nc} C_l = \mathbf{g}_l^T \mathbf{q}_l \quad \text{with} \quad \mathbf{K}\mathbf{q}_l = \mathbf{g}_l \qquad \textit{Linear static analysis}$$

$$\tilde{q}_j \leq \bar{q} \qquad \textit{Bounded displacement at node j}$$

$$\sum_i \mu_i V_i \leq \bar{V} \qquad \textit{Bounded volume}$$

$$0 < \underline{\mu}_i \leq \mu_i \leq 1 \qquad \textit{Side constraints}$$

$$\boldsymbol{\mu} = \{\mu_i, i = 1, \ldots, n\}$$

TOPOL software for topology optimization

Classical formulation: maximize stiffness of the structure for a given volume fraction of material required at solution.

For the linear case:

When only displacement constraints are taken into account:

$$\min_{\boldsymbol{\mu}} V \quad \text{with} \quad \mathbf{K}\mathbf{q}_l = \mathbf{g}_l \qquad \textit{Linear static analysis}$$

$$\tilde{q}_j \leq \bar{q} \qquad \textit{Bounded displacement at node j}$$

TOPOL software for topology optimization

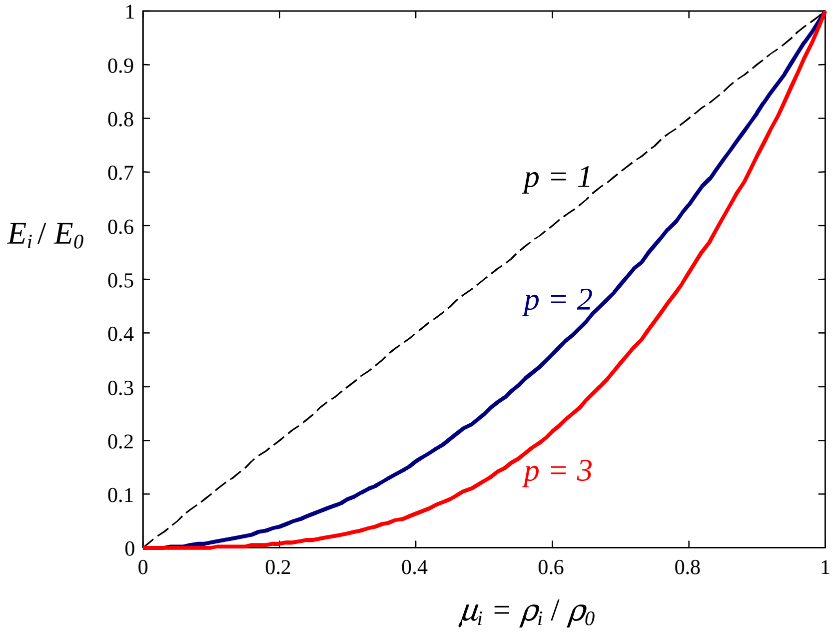
Material law: SIMP => specific parameterization of the material properties

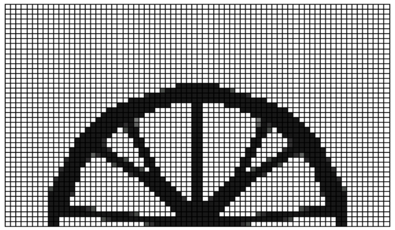
- Mass density $\rho_i = \mu_i \times \rho_0$
- Young modulus $E_i = \mu_i^p E_0$

Base material properties (e.g. aluminium)

$p > 1 \longrightarrow$ to penalize intermediate densities

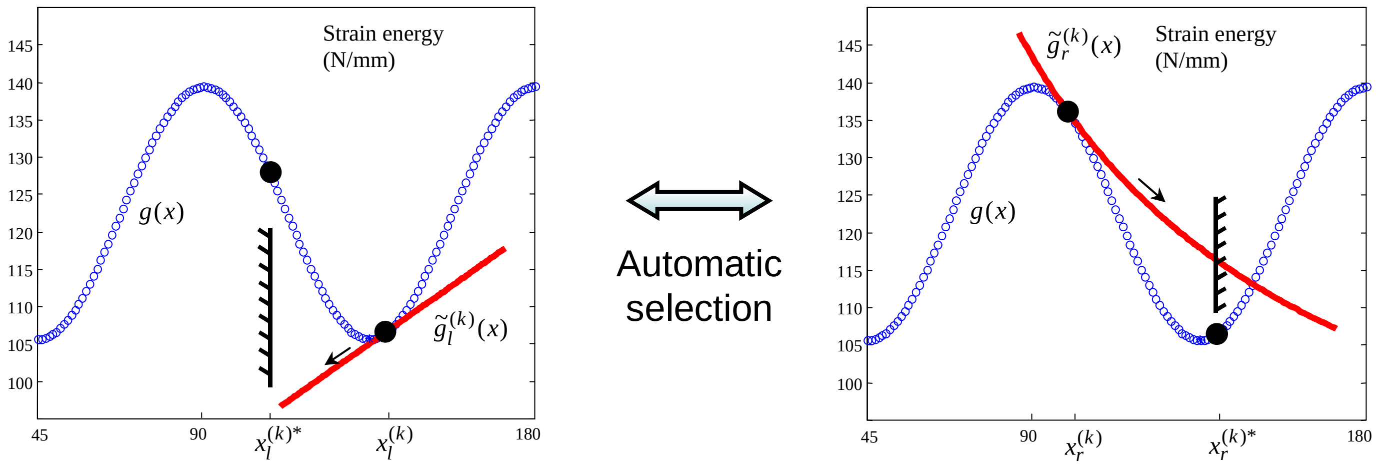
Goal = to have a "black-and-white" final design





Optimisation algorithm

- ***Sequential Convex Programming method***
- Details:
  - Based on **CONLIN** (Fleury and Braibant, *Int. J. Num. Meth. Engng*., 1986)
  - Generate successive approximations of the initial optimization problem
  - multi-objective formulation (*min max* or *max min*)
  - dual solver



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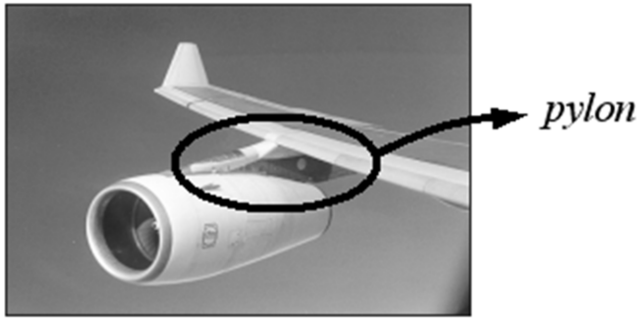
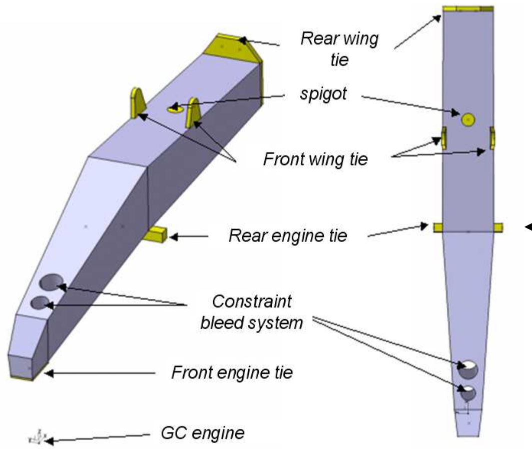
Original designs of Airbus pylons

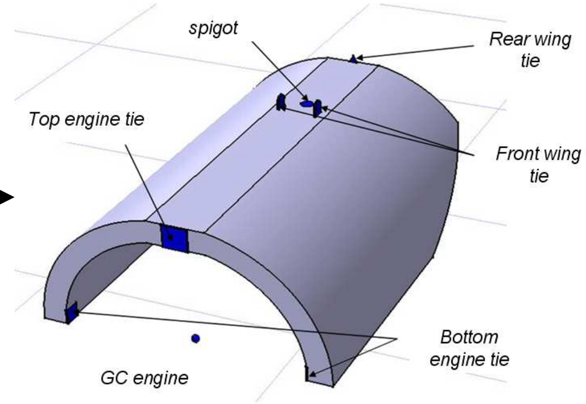
The structure to optimize



Two enveloppes for the design

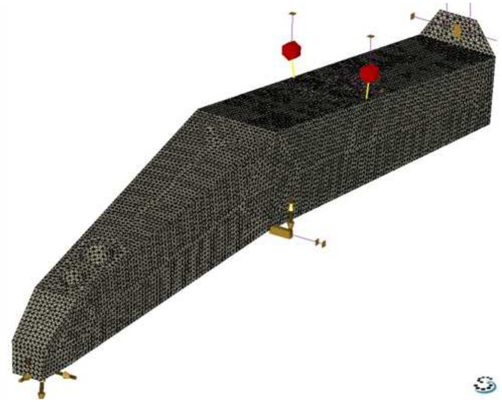


For 2 different aircrafts



Original designs of Airbus pylons

The first design



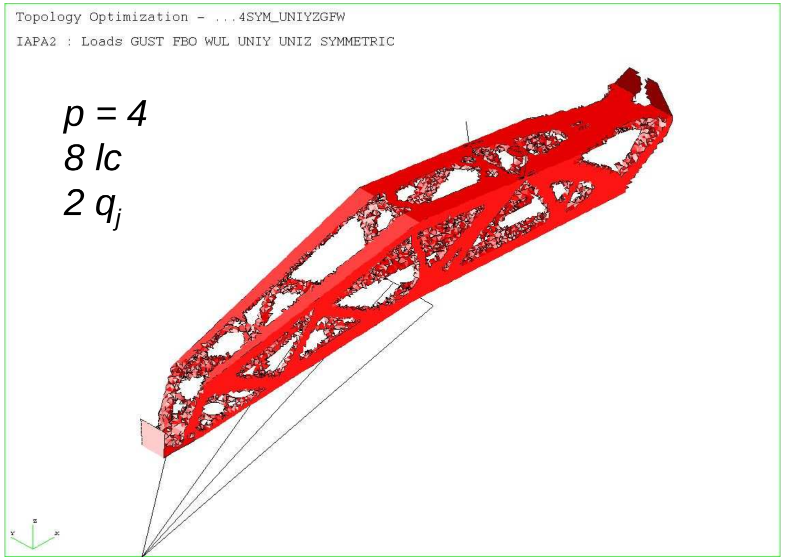
- Number of tetrahedral elements

= Number of design variables = 244021

- 8 static load cases (maneuvers, gust, fan blade off, landing on the engine) + 2 bounded displacements

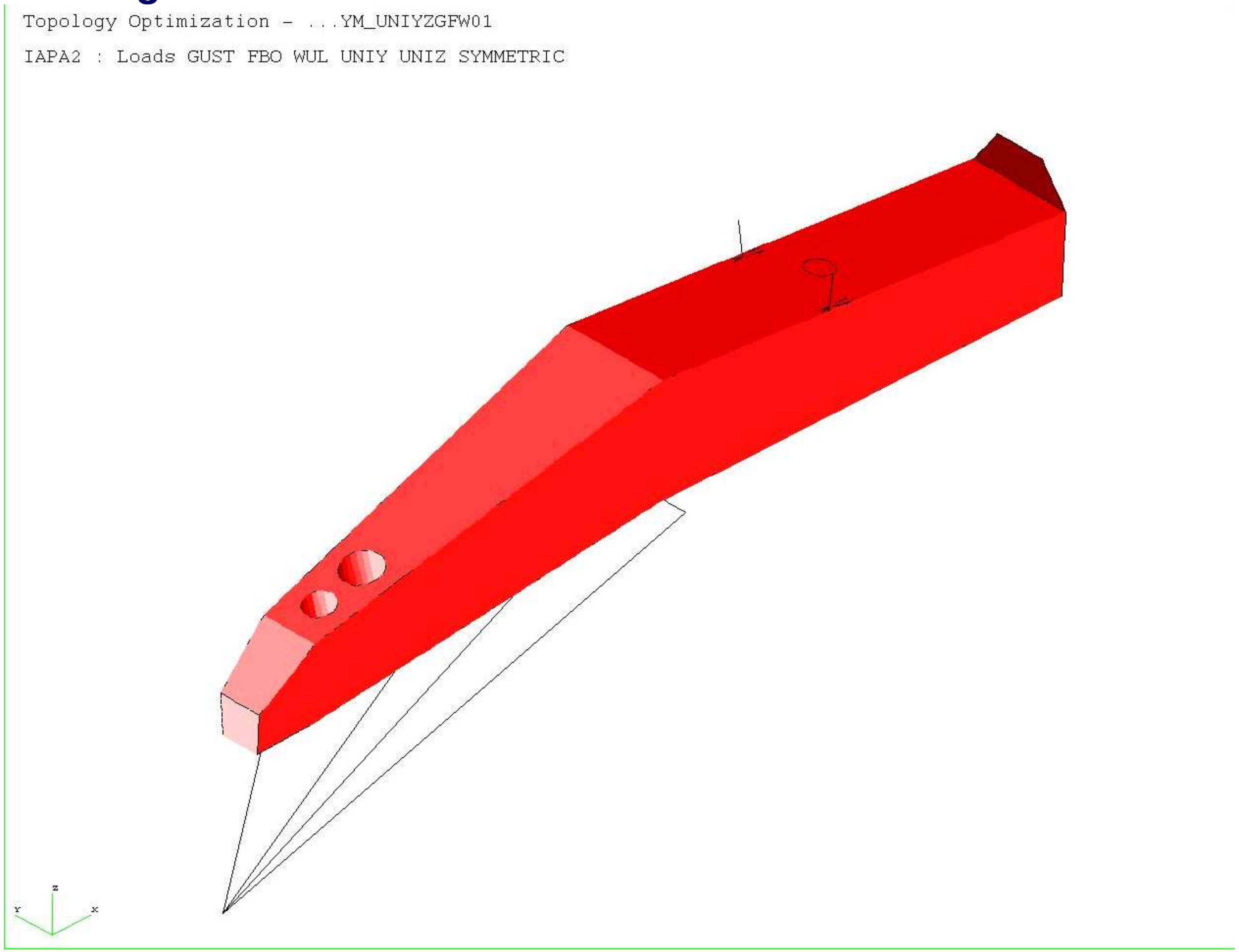
$$\min_{\boldsymbol{\mu}} \max_{l=1,\ldots,8} C_l = \mathbf{g}_l^T \mathbf{q}_l \qquad \text{with} \qquad \sum_i \mu_i V_i \leq 0.1$$

$$\tilde{q}_j \leq \bar{q}$$



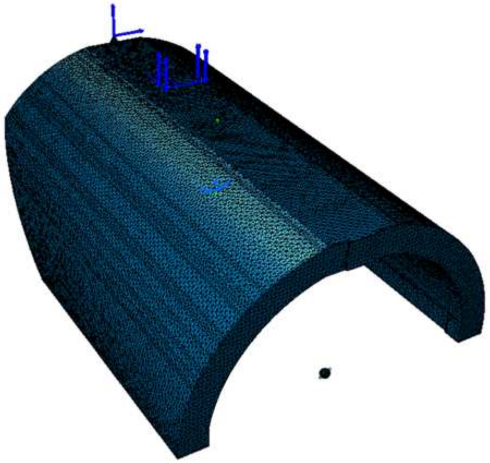
Original designs of Airbus pylons

The first design



Original designs of Airbus pylons

The second design



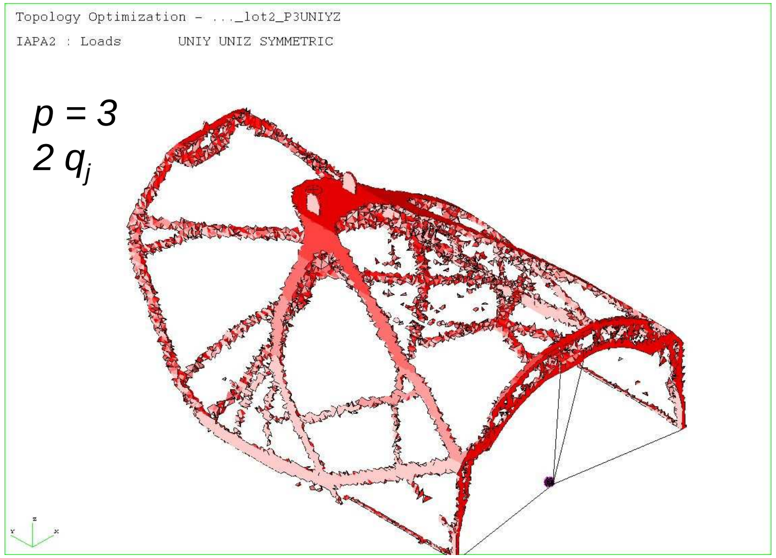
- Number of tetrahedral elements

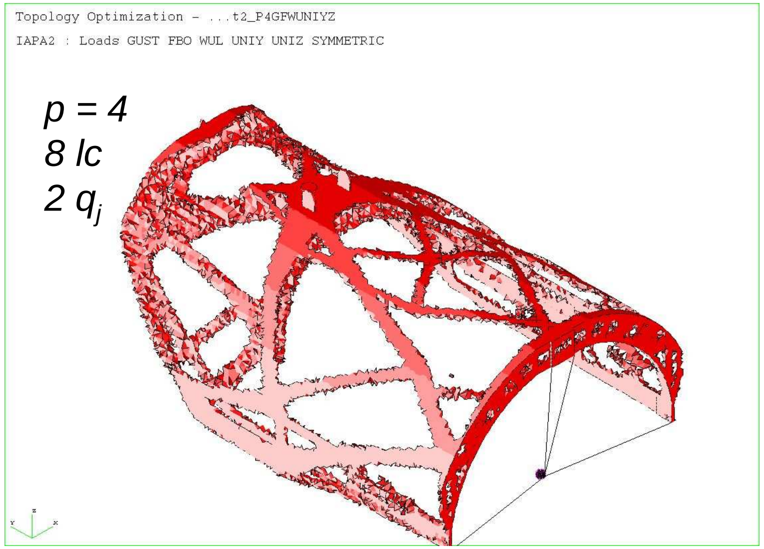
= Number of design variables = 420839

- 8 static load cases (maneuvers, gust, fan blade off, landing on the engine) + 2 bounded displacements

$$\min_{\boldsymbol{\mu}} \max_{l=1,\ldots,8} C_l = \mathbf{g}_l^T \mathbf{q}_l \quad \text{with} \quad \sum_i \mu_i V_i \le 0.1$$

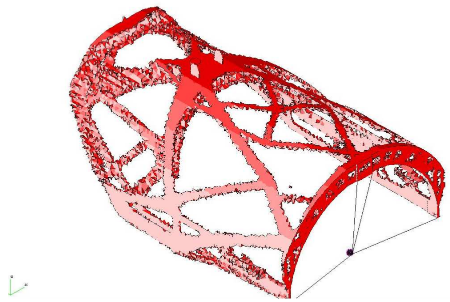
$$\tilde{q}_j \le \bar{q}$$





Original designs of Airbus pylons

The second design



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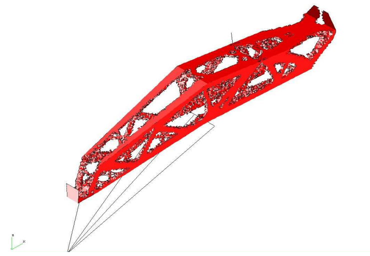
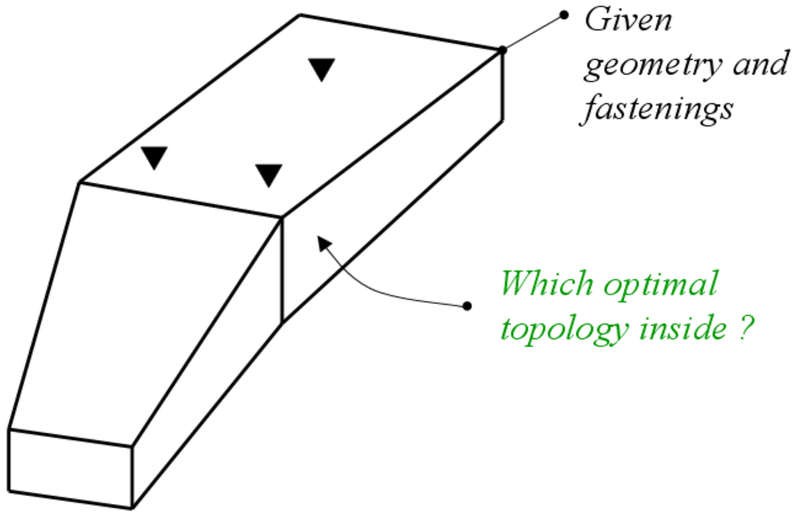
Bi-level optimization

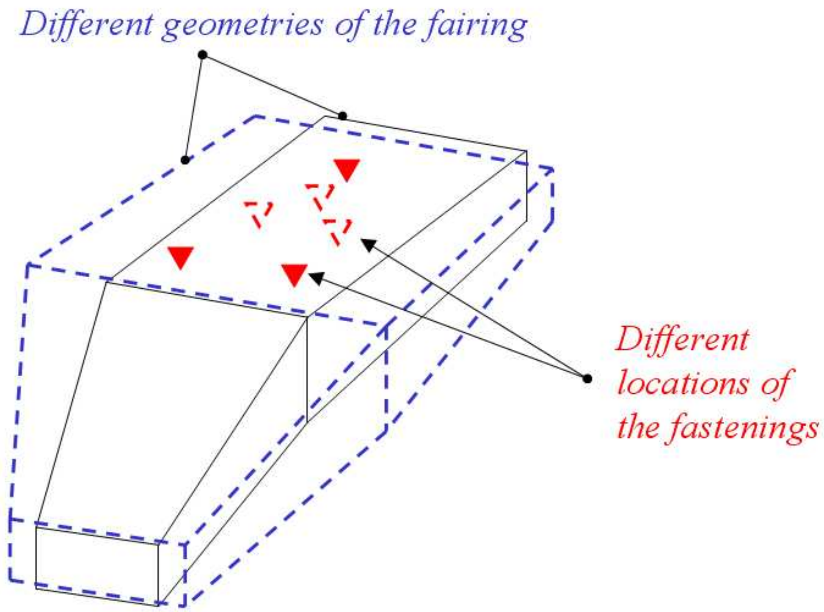
Problem statement

Two kinds of design variables which can be combined:





Topology design variables

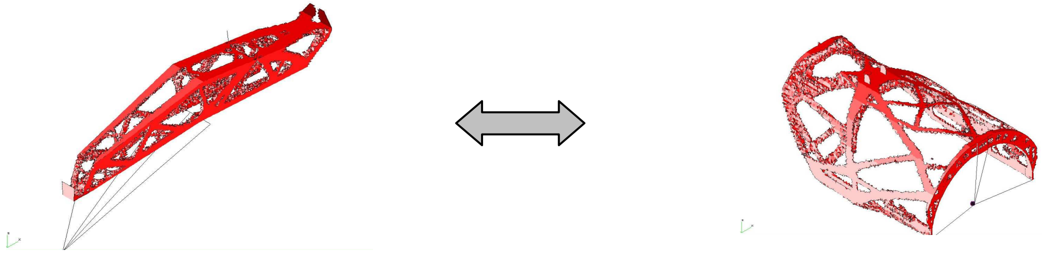


Geometric design variables

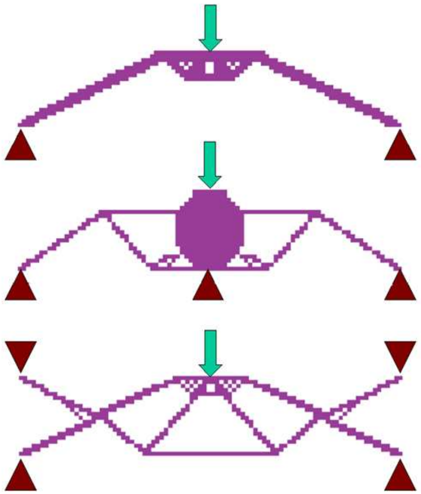
Bi-level optimization

Problem statement

- Influence of the geometry on the optimal topology: observed before.



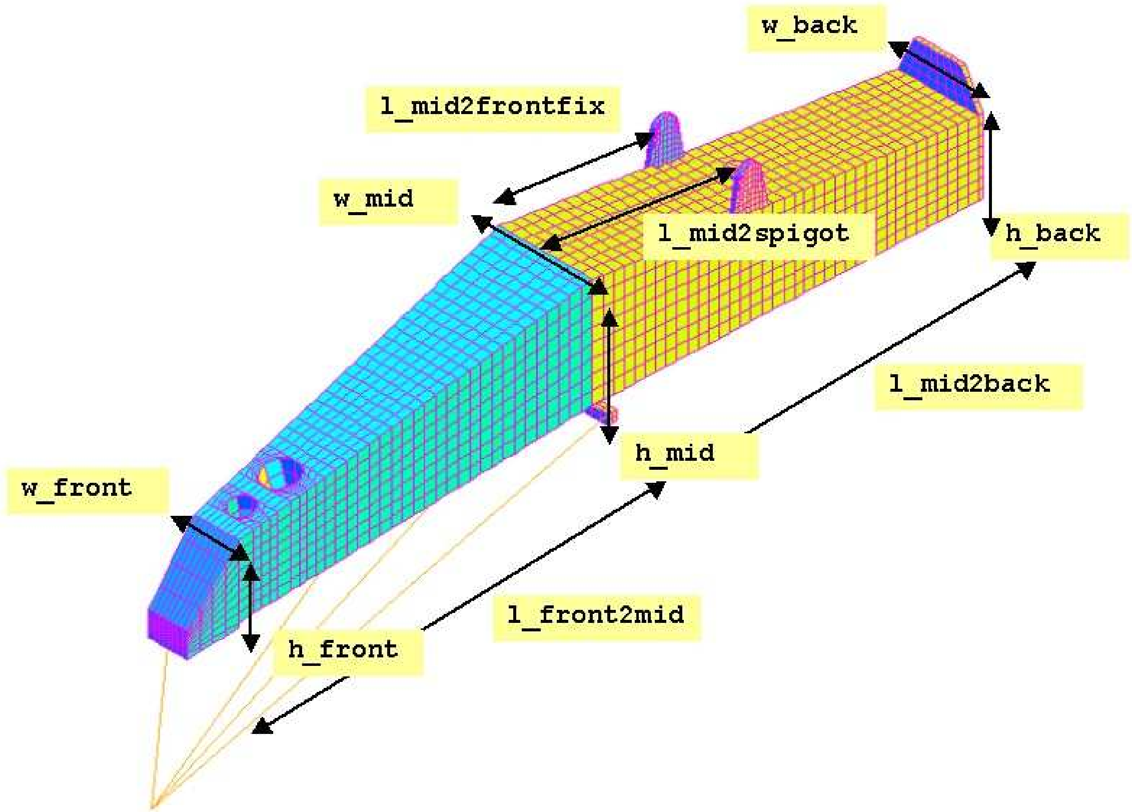
- Influence of the boundary conditions on the optimal topology:



Bi-level optimization

Problem statement

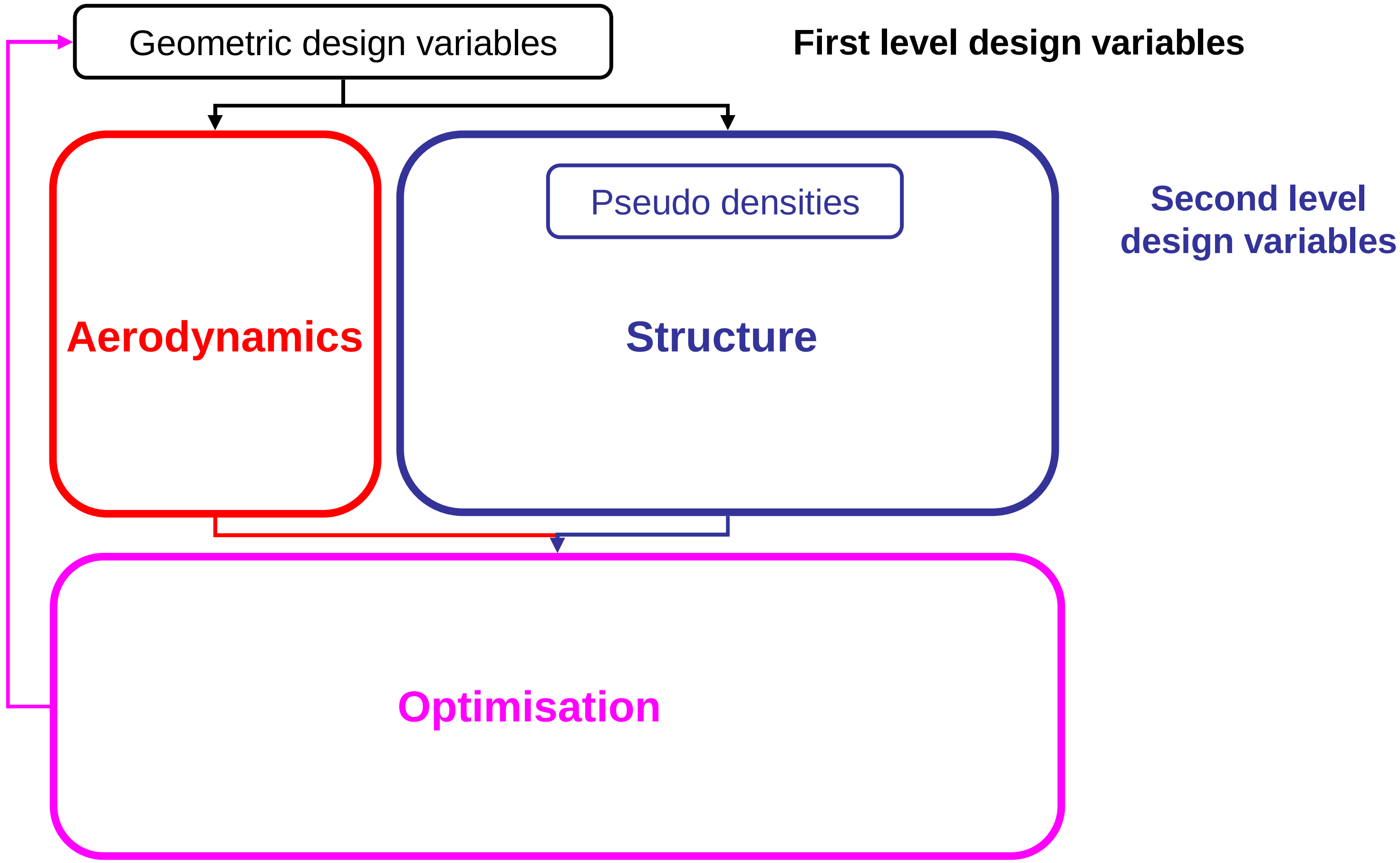
Set of design variables (geometry and fastening):



Bi-level optimization

Problem statement

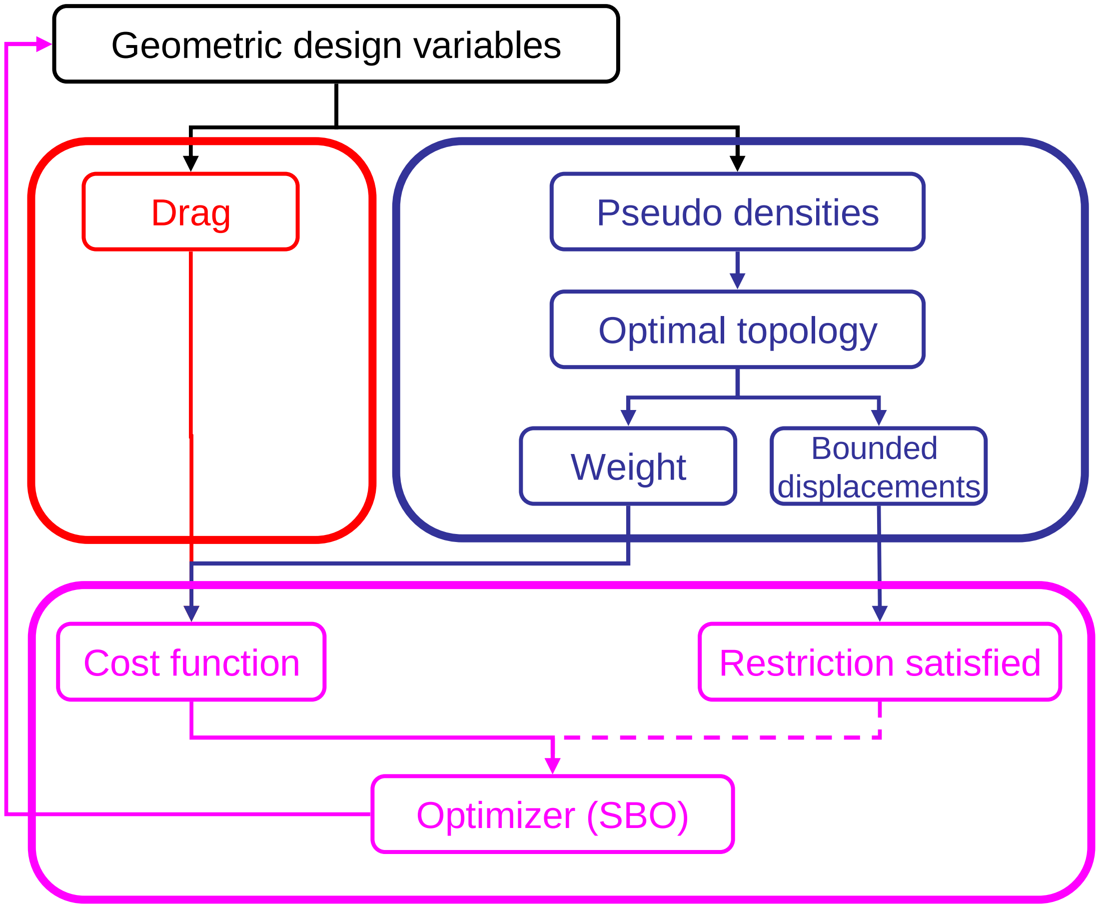
Two disciplines which are considered:



Bi-level optimization

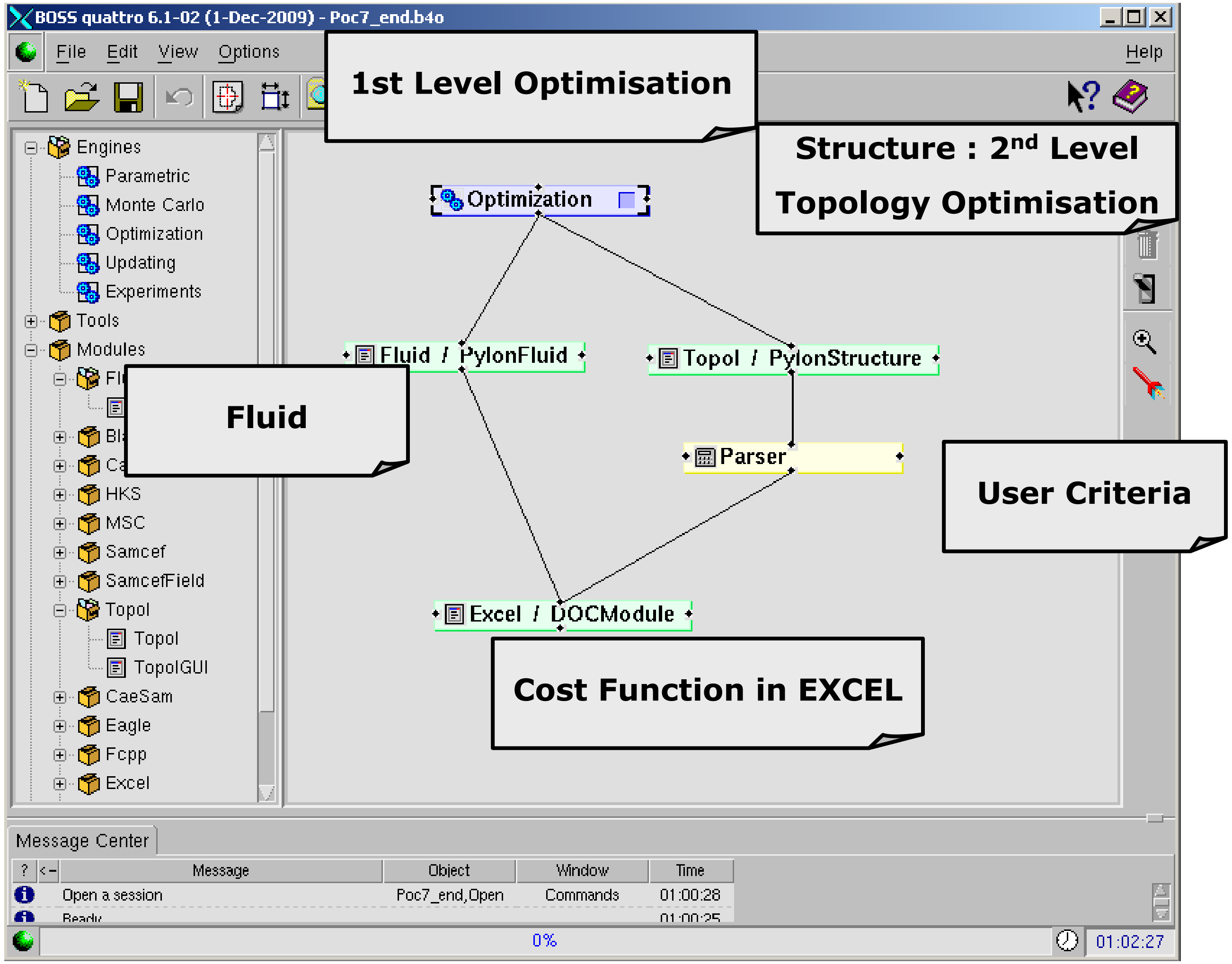
Problem statement

Two disciplines which are considered:



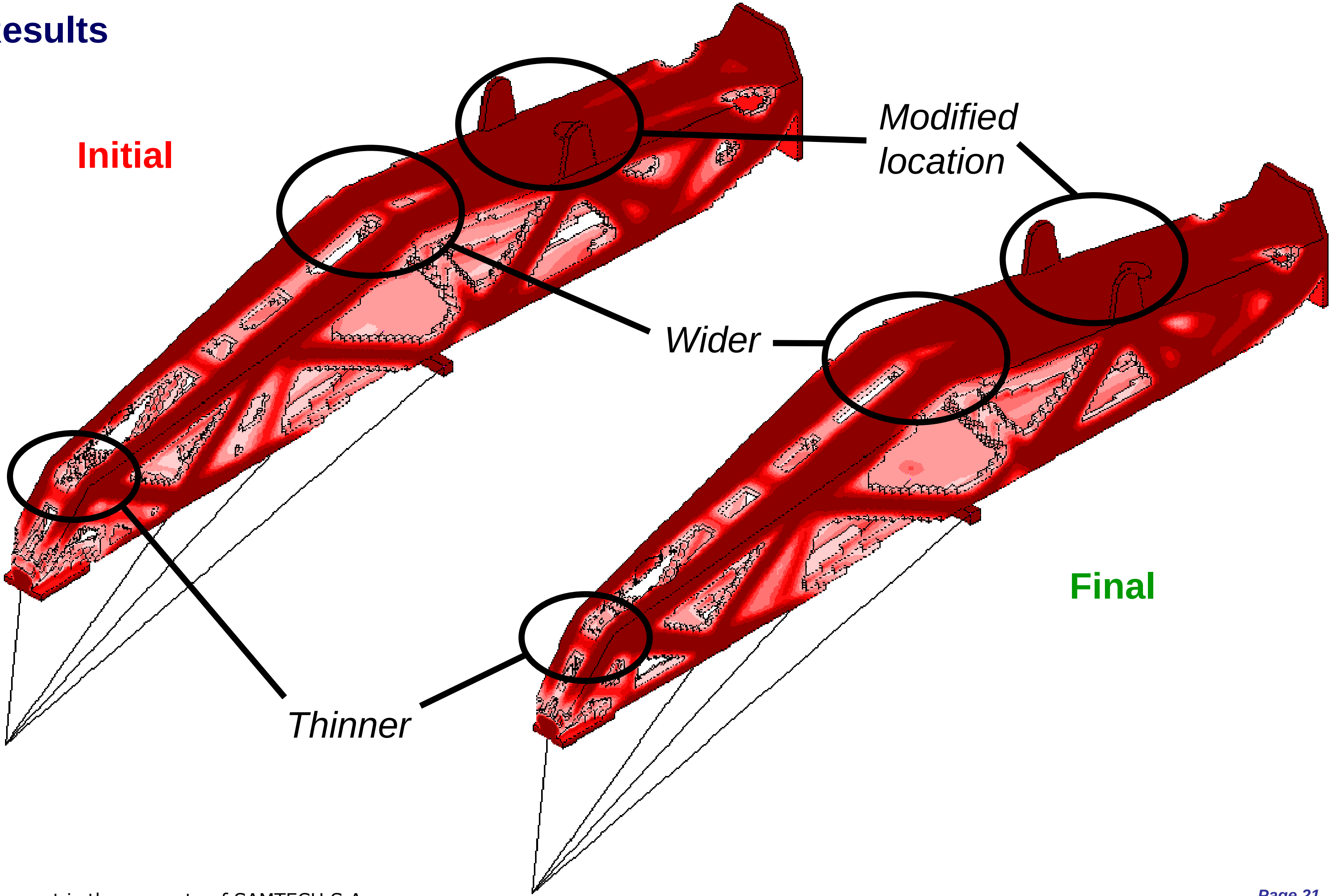
Bi-level optimization

Implementation in the BOSS quattro software



Application

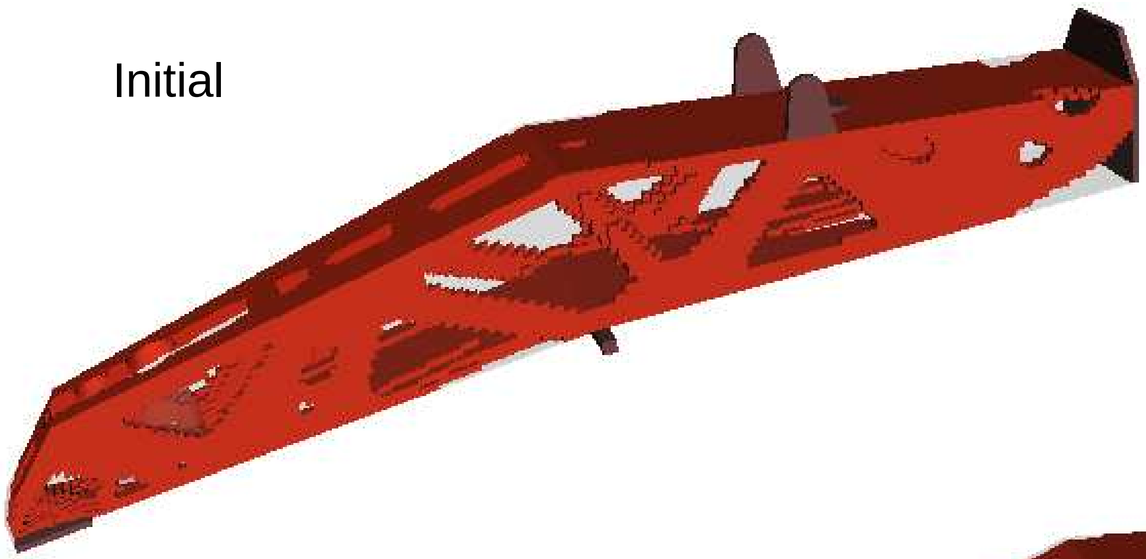
Results

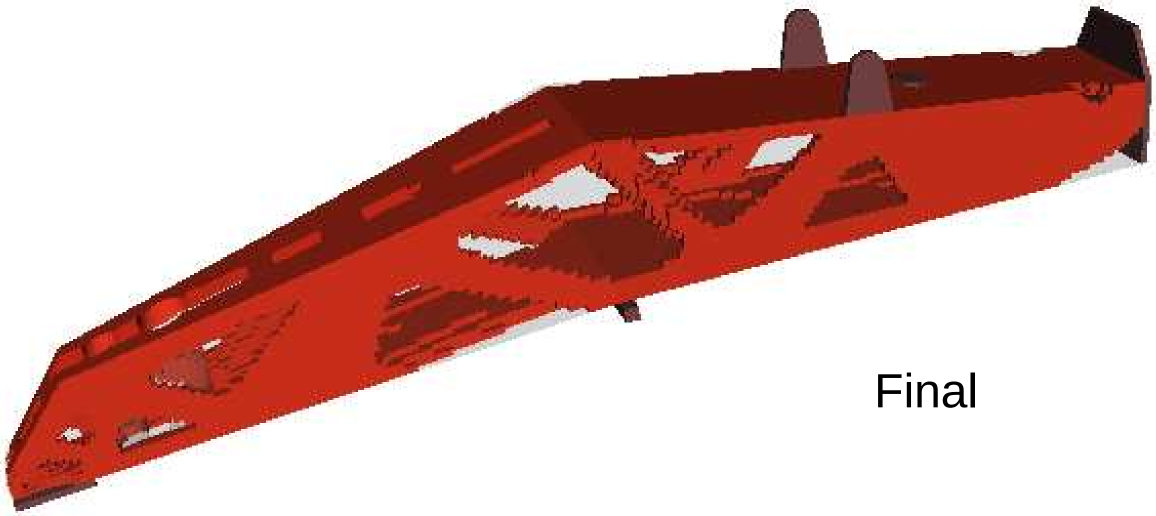


Application

Results

Initial





Final

Conclusions

- Original designs of Airbus pylons have been presented
- Bi-level optimization scheme has been presented
    - includes topology optimization
    - includes shape optimization (+ location of the boundary conditions)
    - multidisciplinary optimization
        - aerodynamics
        - structure
    - demonstrated on an Airbus applications
    - applications with other design problems are being investigated

Acknowledgements

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