Abstract

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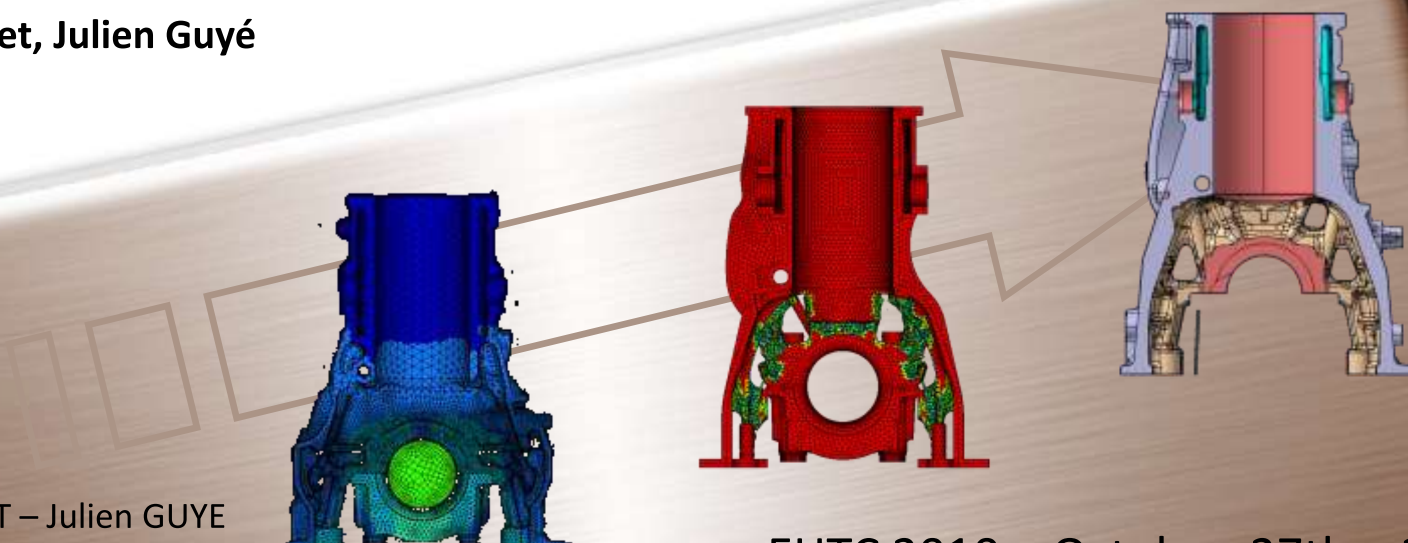
Fatigue topology optimization of a crankcase

Nowadays, CO2 emissions reduction and therefore vehicles mass reduction must be taken into account in the design process. Topology optimization tools are powerful levers to achieve lighter and more reliable conceptions. In the automotive field, the fatigue strength of parts is predominant and often drives the design. Thus, taking into account this mechanical behaviour is essential in the optimization calculation. This paper describes the first use of this new OptiStruct feature, applied to a crankcase.

Bernard Charlet, Julien Guyé



Agenda

- Introduction : PSA Peugeot Citroën, Mass and CO_2 emissions reduction
- Crankcase description
- Optimization approach
  - Bolt tightening
  - Fatigue formulation
  - First optimization formulation
  - Final optimization formulation
- Results and discussion
- Conclusion

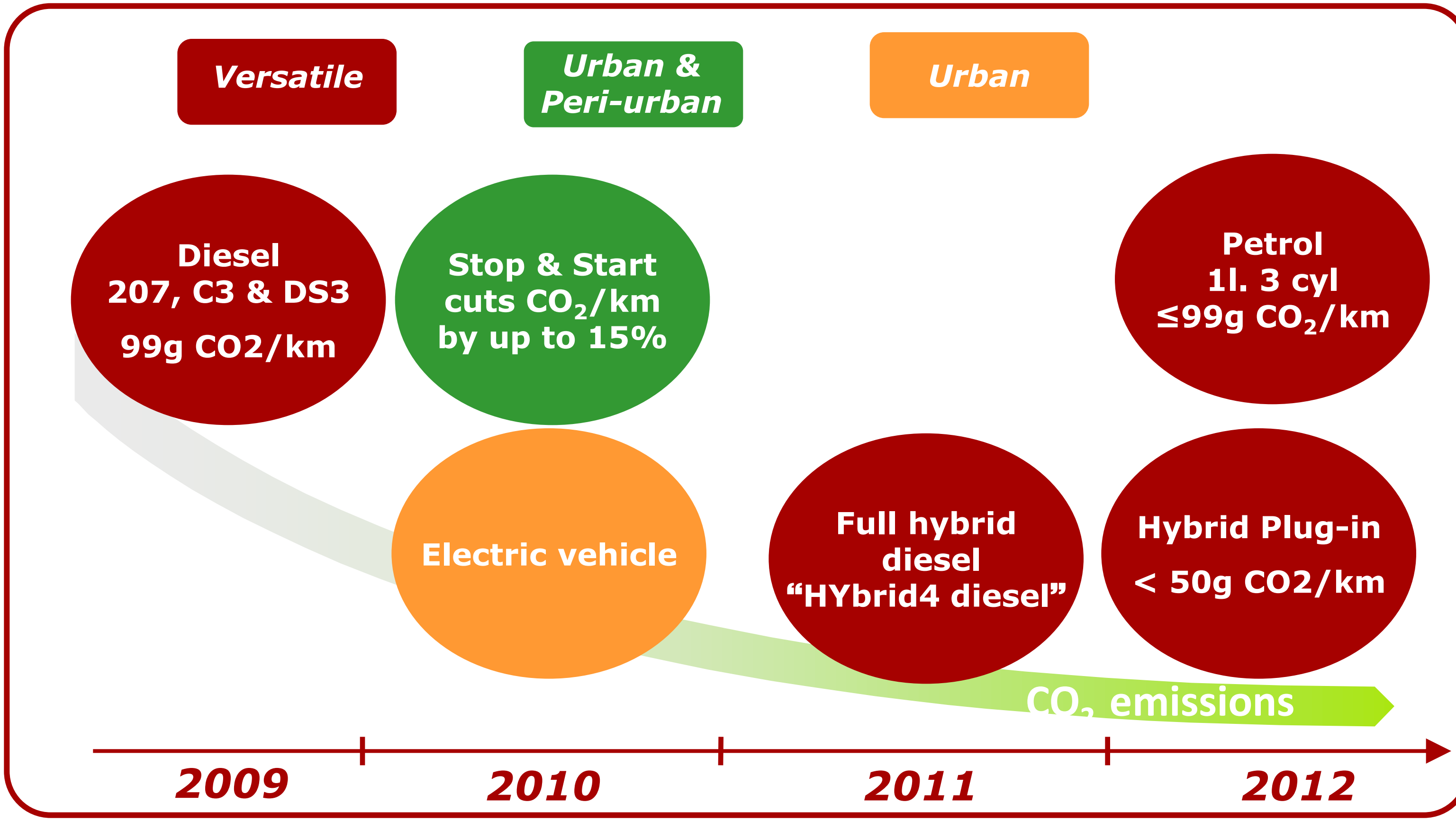
PSA Peugeot Citroën : Key figures (2009)

- Turnover **of €48,4 bn***
- **3,188,000 vehicles** sold worldwide
- **186,220** employees worldwide
- **Europe's No. 2 vehicle manufacturer** with market share of **13.7%**
- **Environmental leadership** with sales of 1 million vehicles sold in the world emitting less than 130g of CO_2/km
- **Leadership on the light commercial vehicles market**, with market share of 22.2%




Turnover at the end of 2009

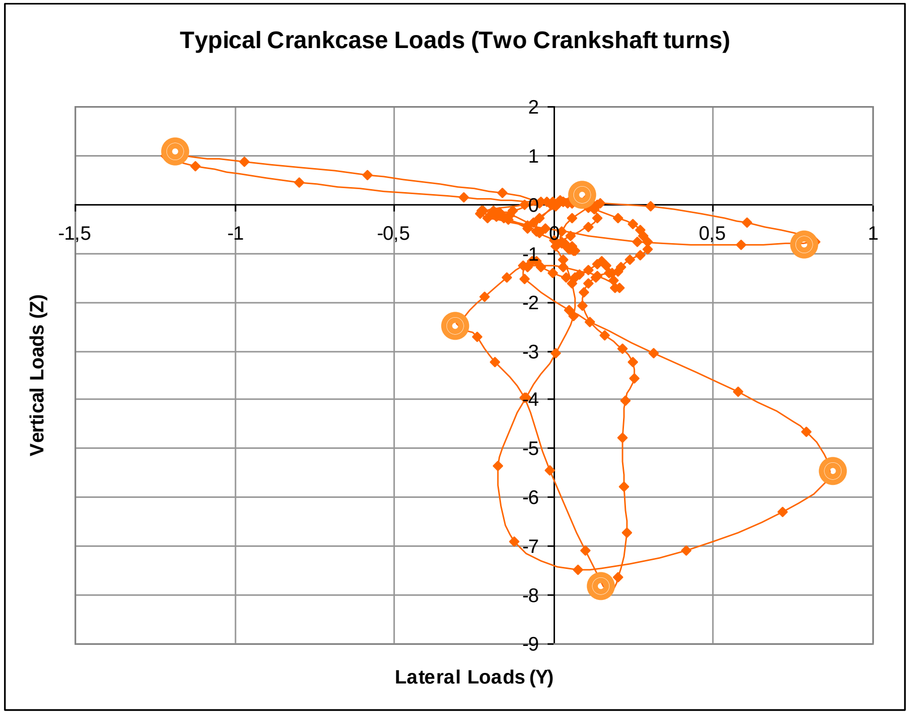
Mass en CO2 emissions reduction : a priority

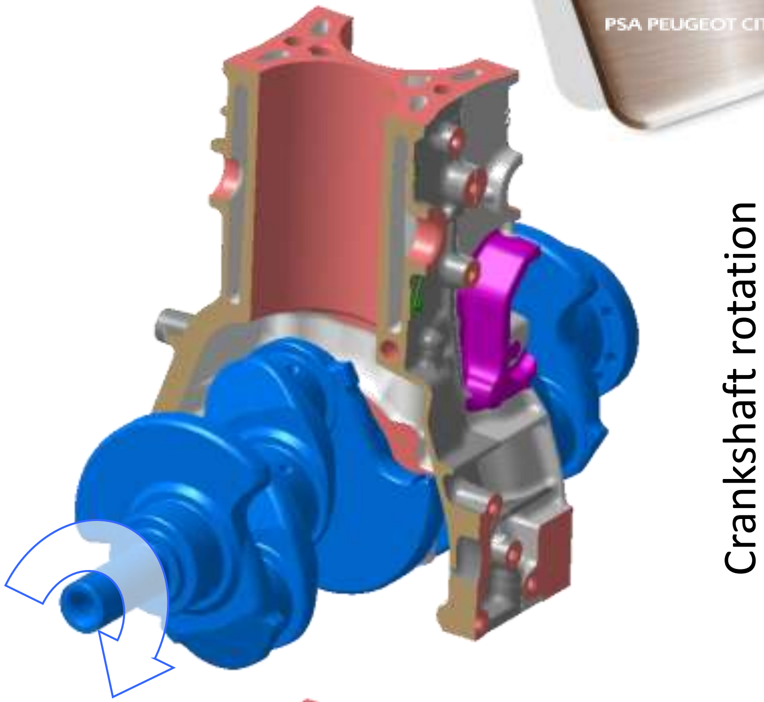


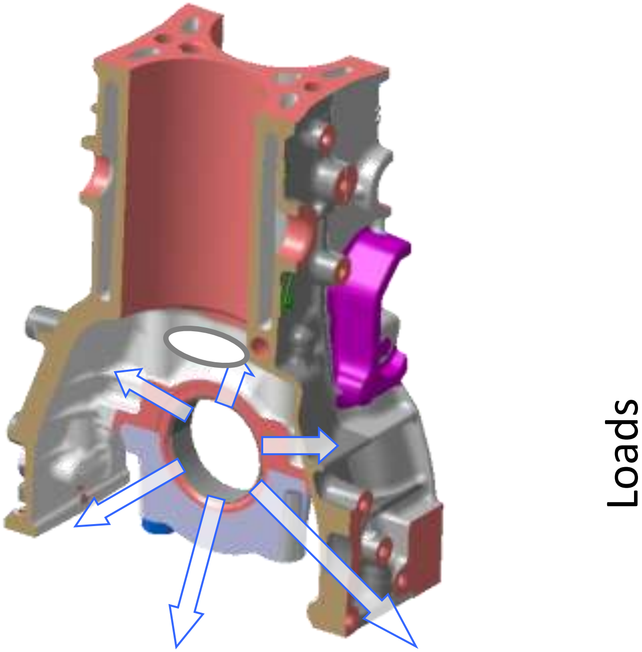
*average emissions in HY1 2009

Crankcase description

- A massive metal part
  - Aluminium or cast iron made
  - Subject to crankshaft rotating loads



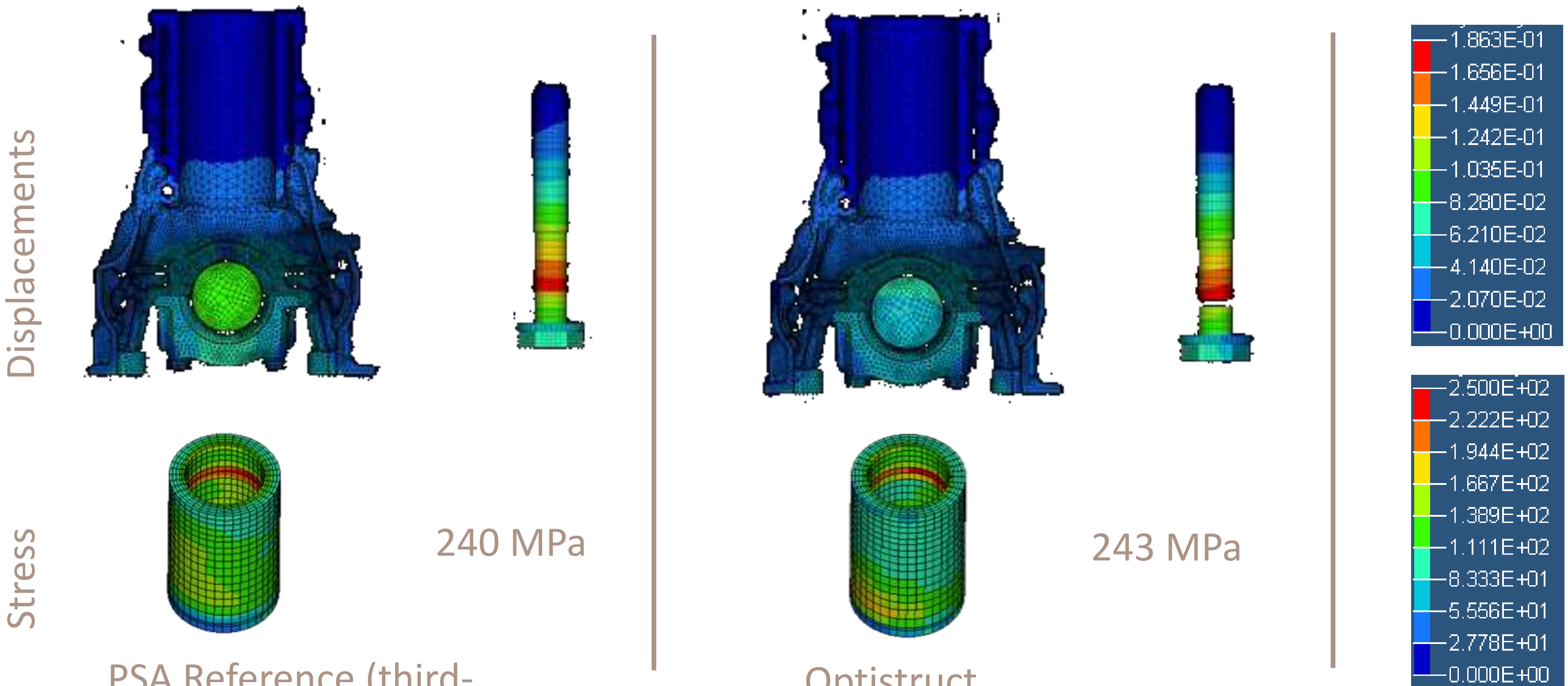




  - Design is driven by fatigue resistance
  - Functional requirement : vent hole is needed

Optimization approach : Bolt tightening

- Optistruct model with contact and bolt tightening
  - By using GAP element with F0



PSA Reference (third-party non linear solver)

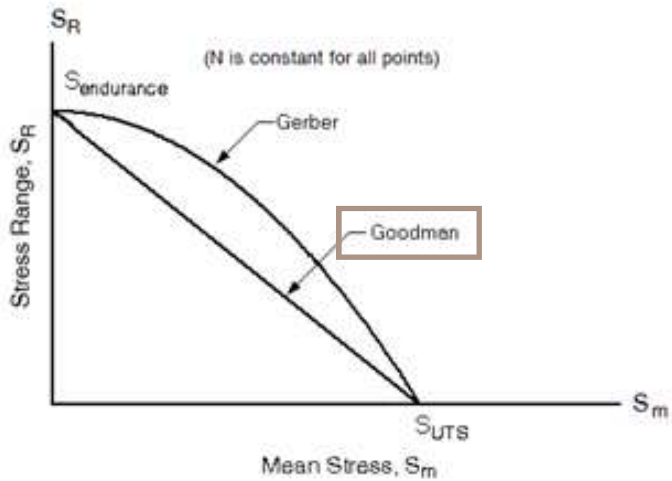
Optistruct

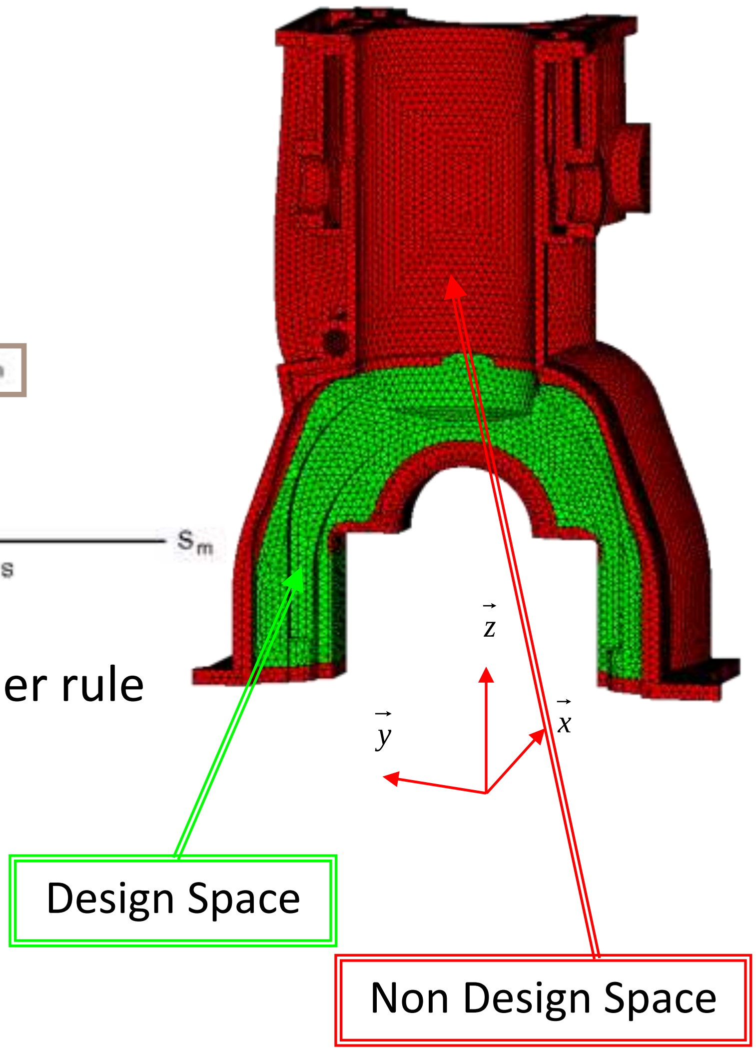
→ First application of bolt tightening – Real improvement

Optimization approach : Fatigue formulation

- SN-Method
  - Based on the Von Mises Equivalent Stress
  - Mean stress correction (Goodman)

$$S_e = \frac{S_a}{1-(S_m / S_u)}$$





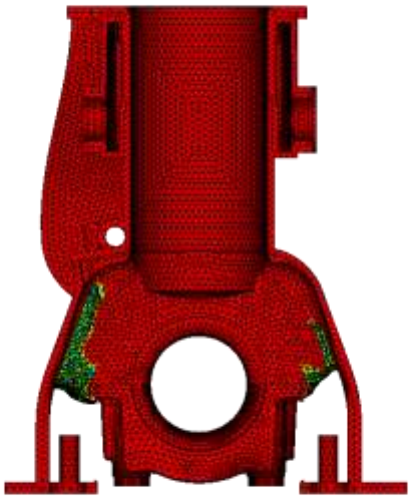
  - Damage accumulation with Palmgreen Miner rule

$$\sum D_i = \sum \frac{n_i}{N_{if}} < 1.0$$

Optimization approach : First optimization formulation

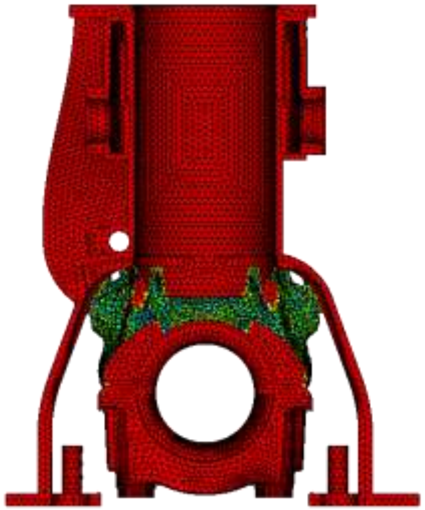
- Two « natural » approaches :
  - Formulation 1 : Mass minimization
    - With lifetime > $1^{E}6$ cycles (DS + NDS)
    - With split draw direction along crankshaft axis

→ Limited mass removal : solver needs more guidelines



  - Formulation 2 : Compliance minimization
    - With Volfrac < 20 %
    - With lifetime > $1^{E}6$ cycles (DS + NDS)
    - With split draw direction along crankshaft axis

→ Real mass removal, but lifetime constraint **is violated** (lifetime less than $1^{E}4$ cycles)



Density Results

Optimization approach : Last optimization formulation

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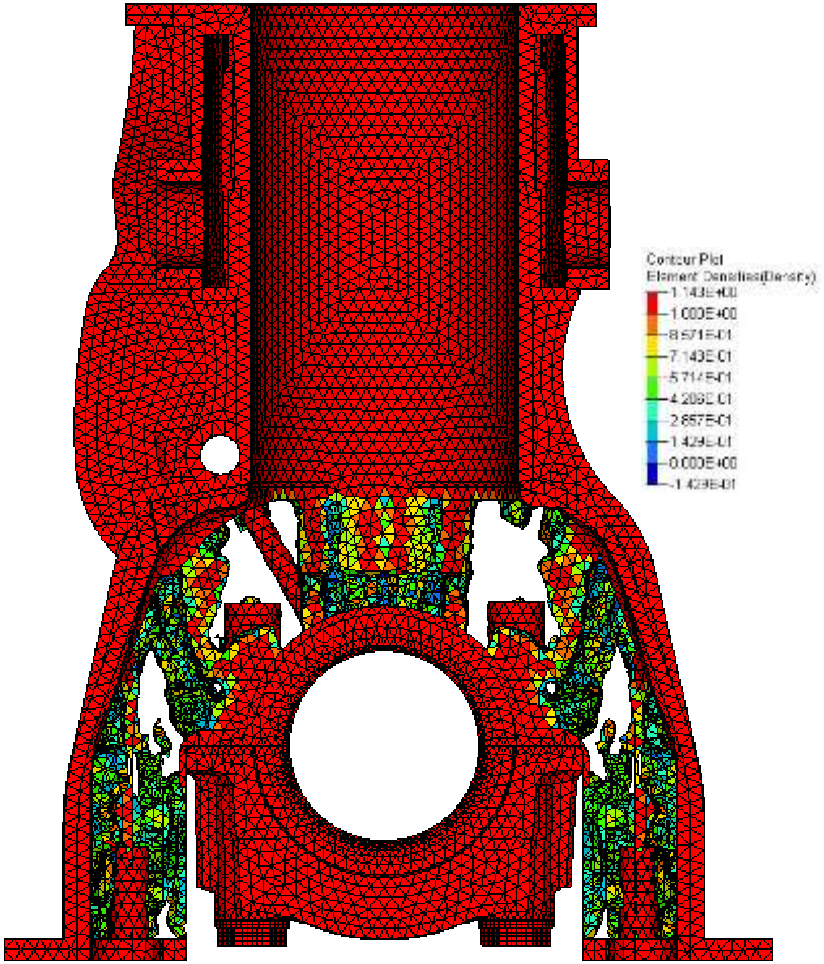
- Other constraints have been added :

  - Objective : compliance minimization
  - Constraint n°1 : lifetime > 1E6 cycles (DS + NDS)
  - Process constraint n°1 : split draw direction along crankshaft axis
  - Process constraint n°2 : Maximum member size of 20 mm

  Functional requirements

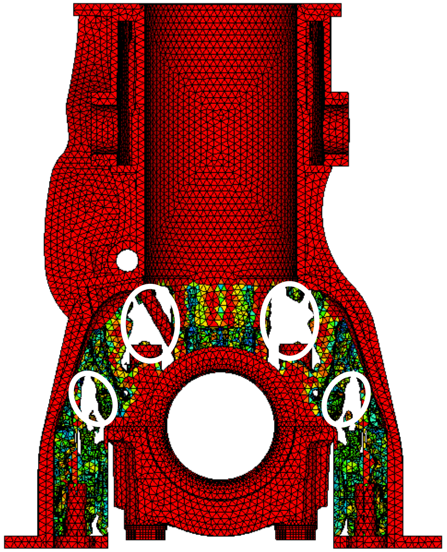
  - Constraint n°2 : Volfrac < 40 %
  - Constraint n°3 : Von Mises Stress in some areas of Non Design Space < 120 MPa to guaranty lifetime

  Solver guidelines



*Life time is at least **2.8e6** cycles*

Results and discussion : optimization results



- Lifetime is respected
  - Only if a Von Mises Stress constraint is added
- Optimization formulation is a bit tricky
  - Constraint on Von Mises Stress must be finely tuned to obtain correct lifetime and an acceptable mass reduction
- No central vent hole suggested by Optistruct, but a real potential for lateral vent holes (2 or 4)
- Topology is naturally almost symmetric :

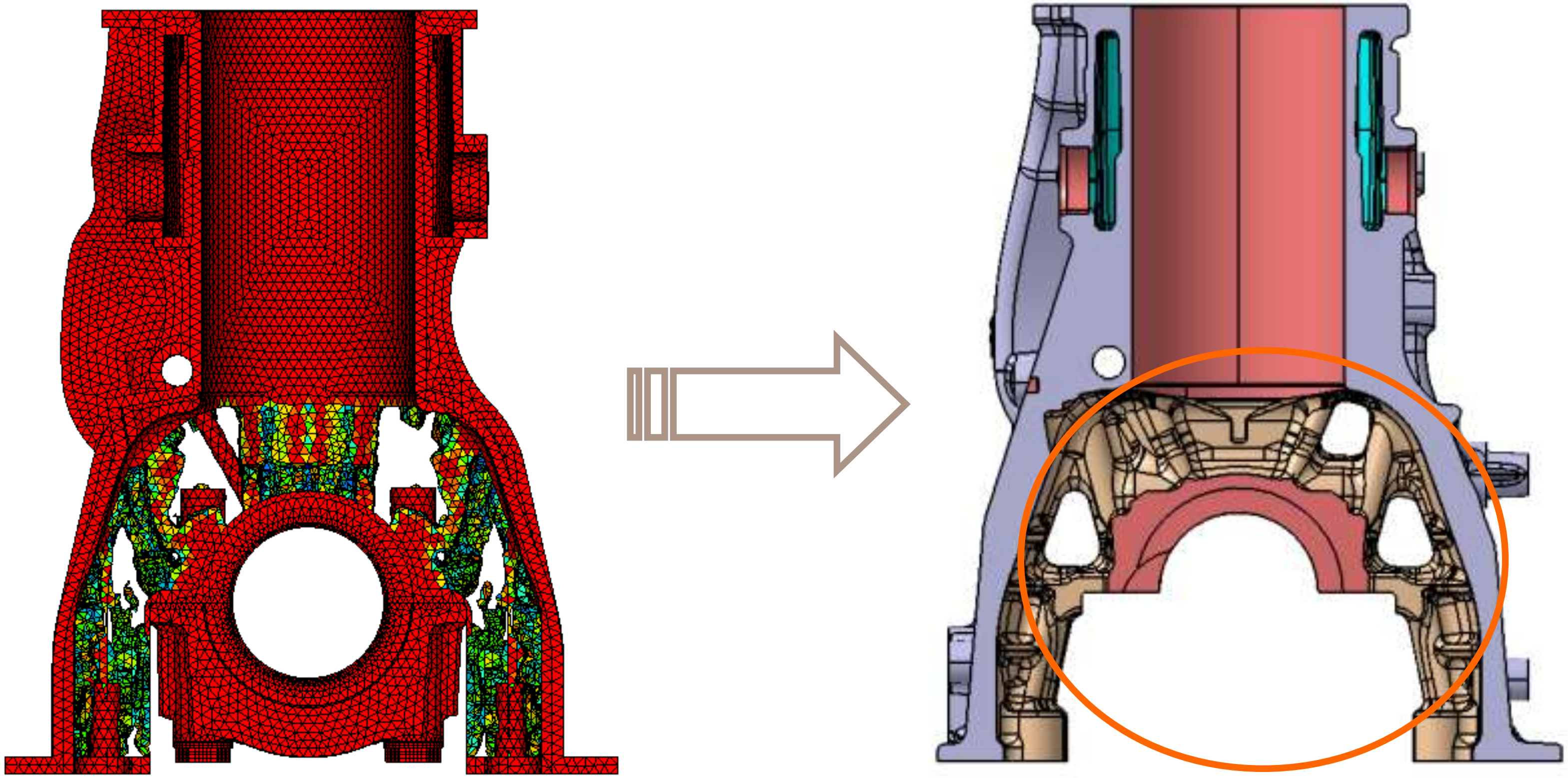
Only split draw direction

Split draw direction + 1 symmetry constraint

Split draw direction + 2 symmetry constraint

Results and discussion : interpretation

- A reconstruction based on Optistruct Result and taking into account detailed process constraints has been done :

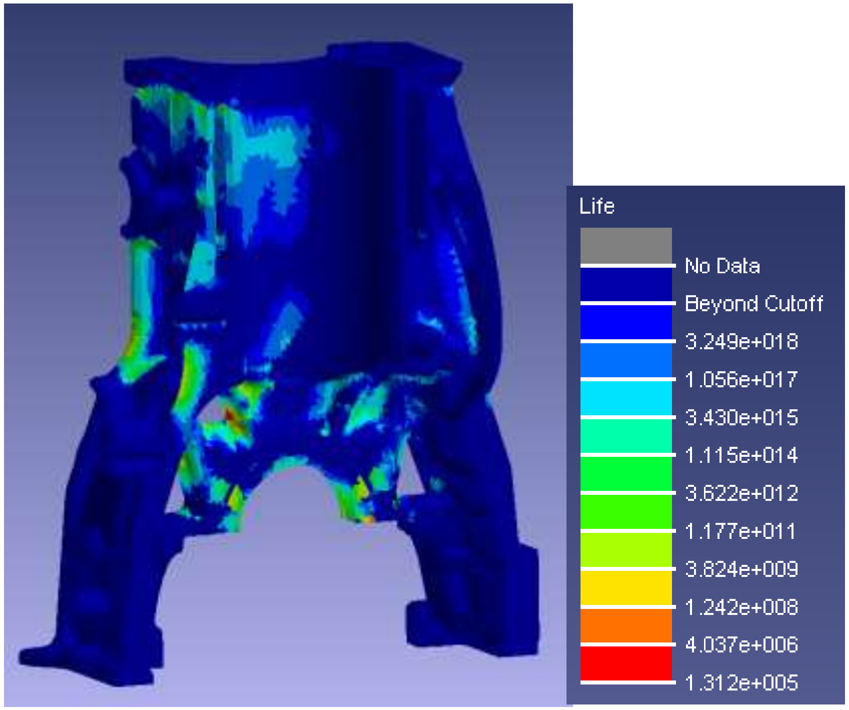


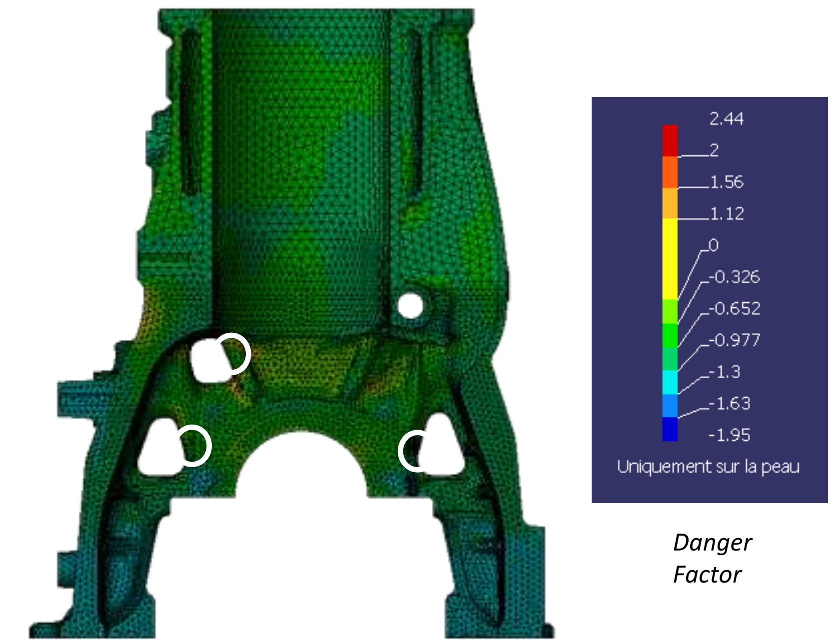
→ **40 %** mass reduction in the Design Space (compared to initial Design Space)

→ **10 %** mass reduction in the area of interest compared to a classical designed definition (almost 3 % on the entire crankcase)

Results and discussion : validation of the final design

- Fatigue resistance evaluations have been done, with Optistruct SN method and with PSA reference Method (Dang Van criterion) :





SN method : lifetime > 1^E6 cycles for 50% of parts

≠

Multi axial criterion : areas with safety factor < 1 for more than 1‰ of parts → not acceptable

Results and discussion : summary

- This work reveals a real potential for fatigue topology optimization :
  - This Optistruct feature gave us good results : the validation calculation, realized with the same SN method, predicts an acceptable lifetime, just like Optistruct results
  - A significant mass reduction (about 10 %) in this case
  - A much faster development time (60 % faster) in this case

- But it raises some questions:
  - Why using only a lifetime constraint did not work ?
    - Using a Stress constraint like we did is a bit unnatural…
  - No direct equivalence between fatigue methods
    - We have to be careful of using the right limit to have an acceptable design production wise

→ A positive study assessment, and an important milestone !

Conclusion and perspectives

- In the Automotive field, fatigue is a high priority in part design.
- Optistruct, with this new features, would find more uses
- To really fit our needs, Optistruct could propose more fatigue criterions and methods (and particularly the multiaxial assessment)…
- But it is a really interesting first step !

Thank you for your attention !