RBF Morph
CAE Conference 2022

Cylinder Head FEA Shape Optimisation with RBF Morph

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Project Background

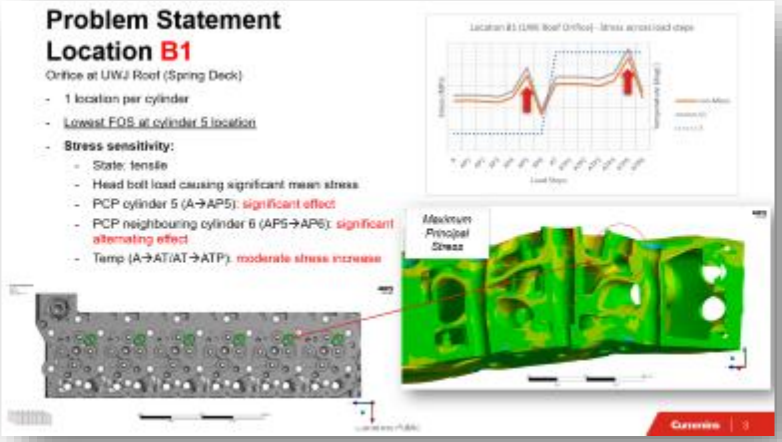
- Cylinder head FEA and Fatigue Analysis
- FEA → Analysis recommendations → design changes → new FEA
- 7 design and analysis iterations had been carried out

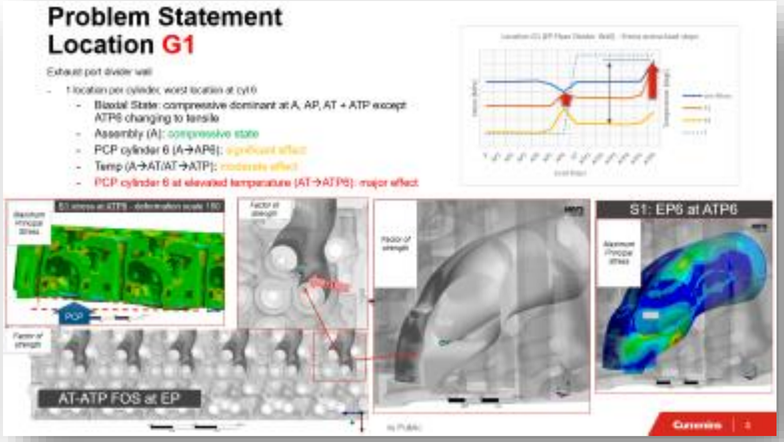
<u>The Problem</u>

- Turnaround time per iteration ~1…2 weeks, often longer (Block-Gasket-Head assembly model)
- Slow improvements made at 2 locations (B1 and G1)

<u>The Solution</u>

- Consequently RBF-morph BGM was employed to speed up the design process
- Benefits of using BGM shape optimisation:
  - Final morphed mesh was exported and used as guideline for redesign
  - Good understanding of limitations of the design before introducing major topology changes
  - Fast turnaround due to one-time model set-up and automated design point progression (all changes occurring on existing mesh and FE-model, cut's out CAD level changes and FE model updating)

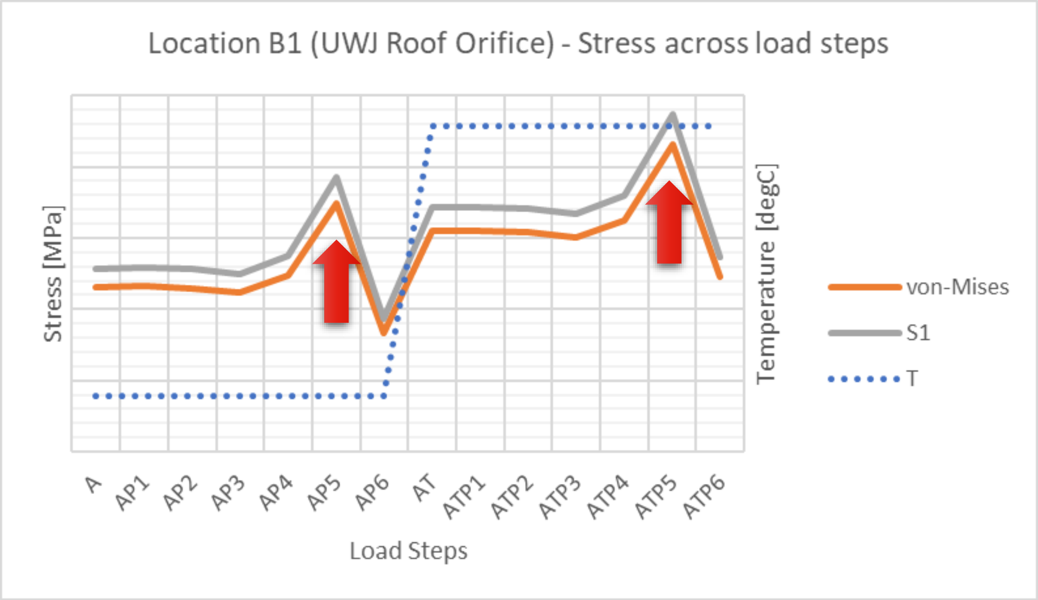


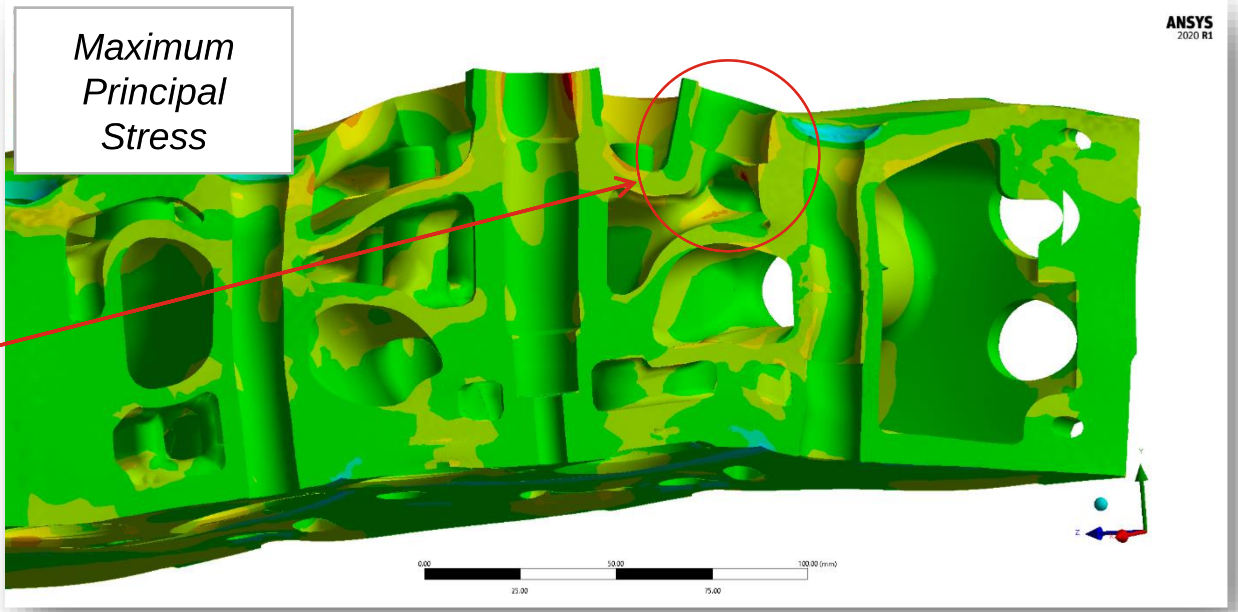


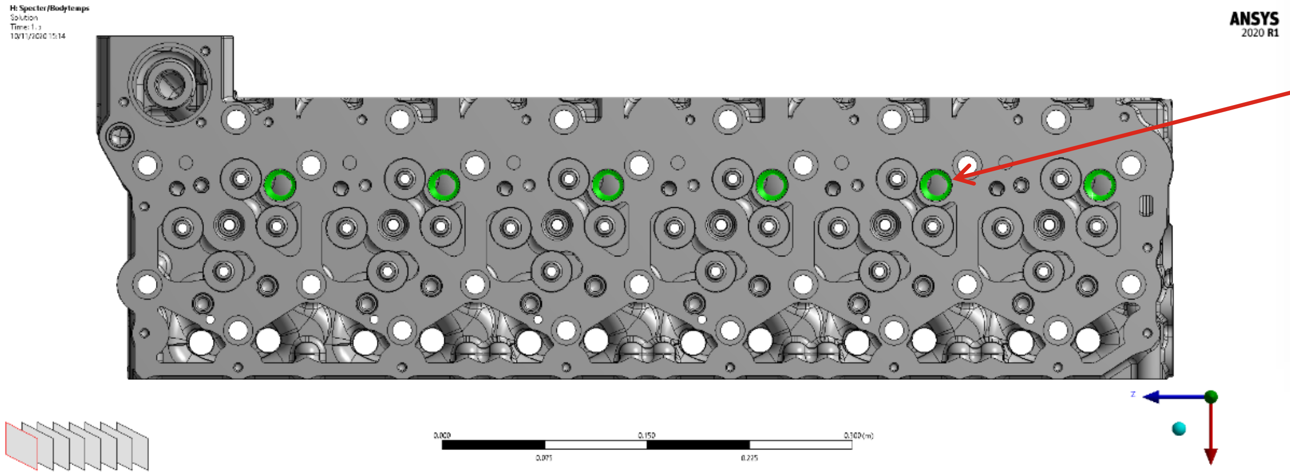
Problem Statement
Location B1

Orifice at UWJ Roof (Spring Deck)

- 1 location per cylinder
- Lowest FOS at cylinder 5 location
- **Stress sensitivity:**
  - State: tensile
  - Head bolt load causing significant mean stress
  - PCP cylinder 5 (A→AP5): significant effect
  - PCP neighbouring cylinder 6 (AP5→AP6): significant alternating effect
  - Temp (A→AT/AT→ATP): moderate stress increase



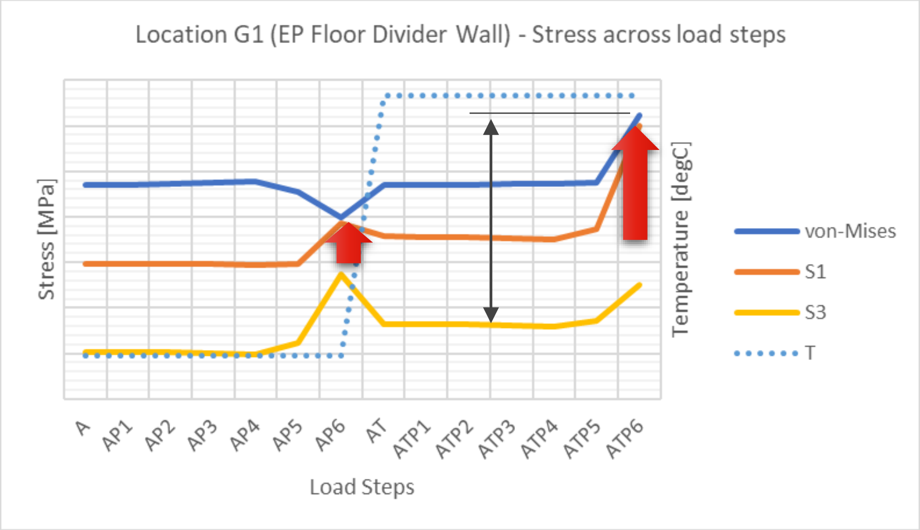


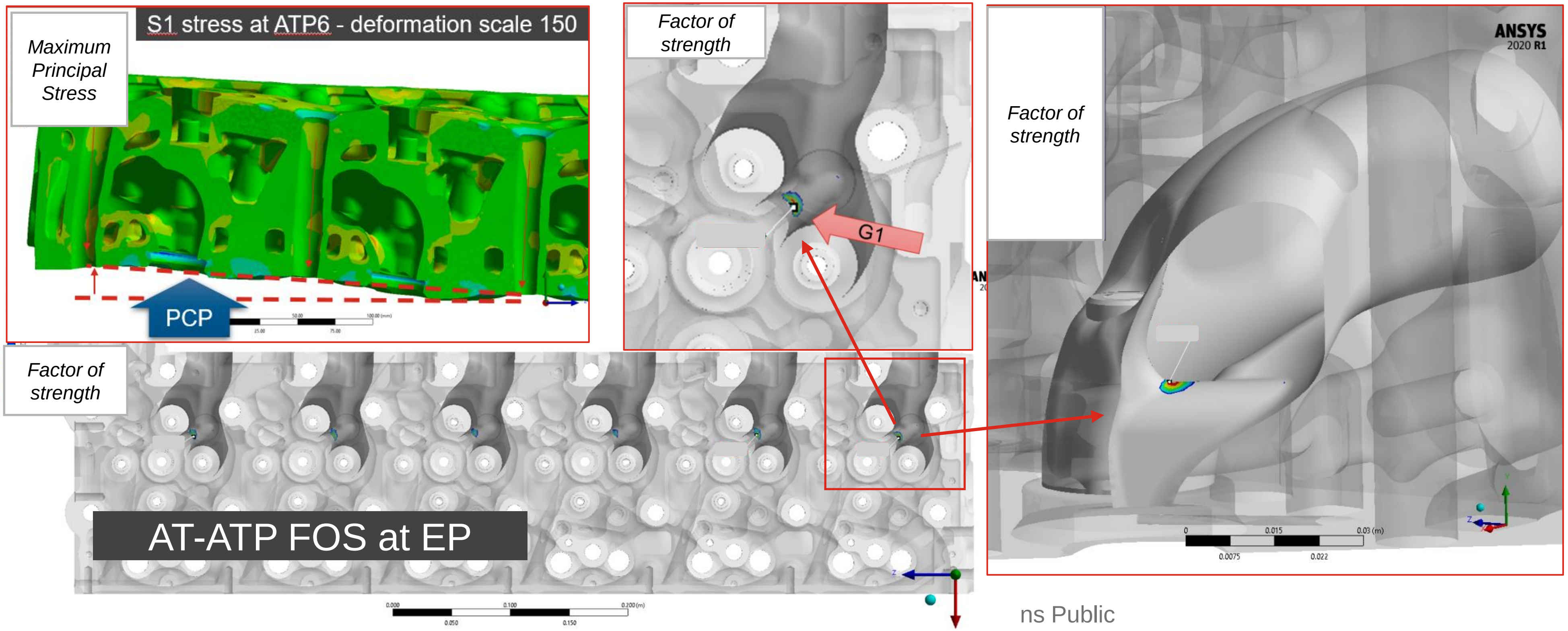


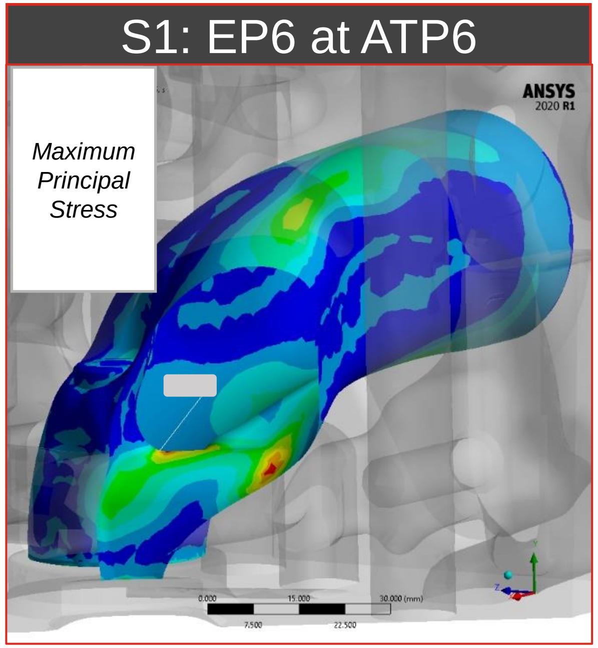
Problem Statement
Location G1

Exhaust port divider wall

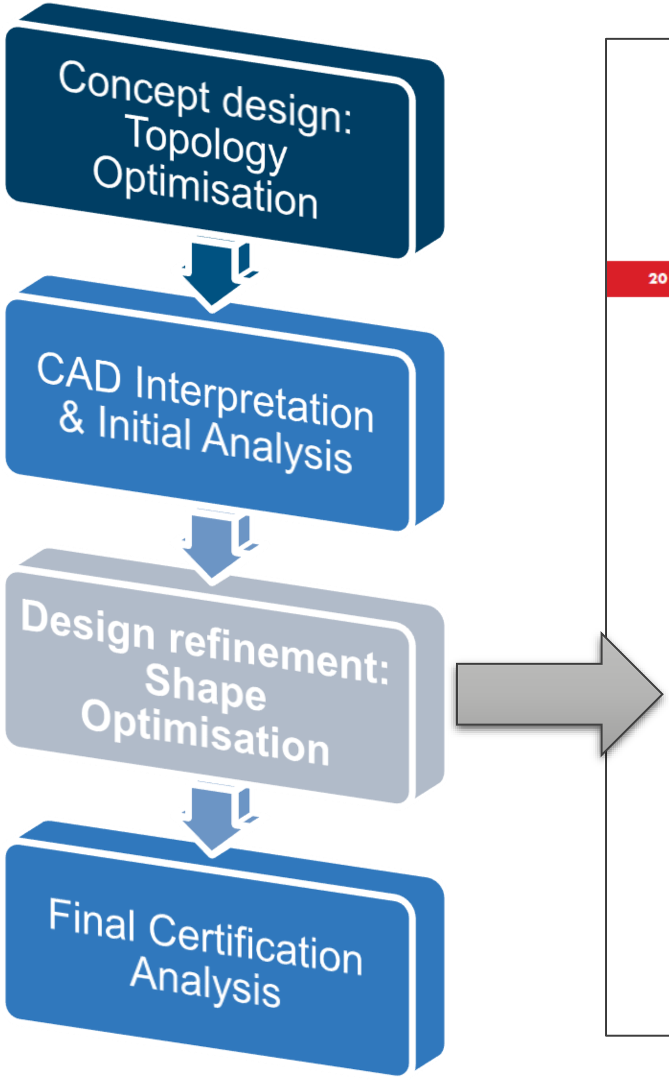
- 1 location per cylinder, worst location at cyl 6
  - Biaxial State: compressive dominant at A, AP, AT + ATP except ATP6 changing to tensile
  - Assembly (A): compressive state
  - PCP cylinder 6 (A→AP6): significant effect
  - Temp (A→AT/AT→ATP): moderate effect
  - PCP cylinder 6 at elevated temperature (AT→ATP6): major effect

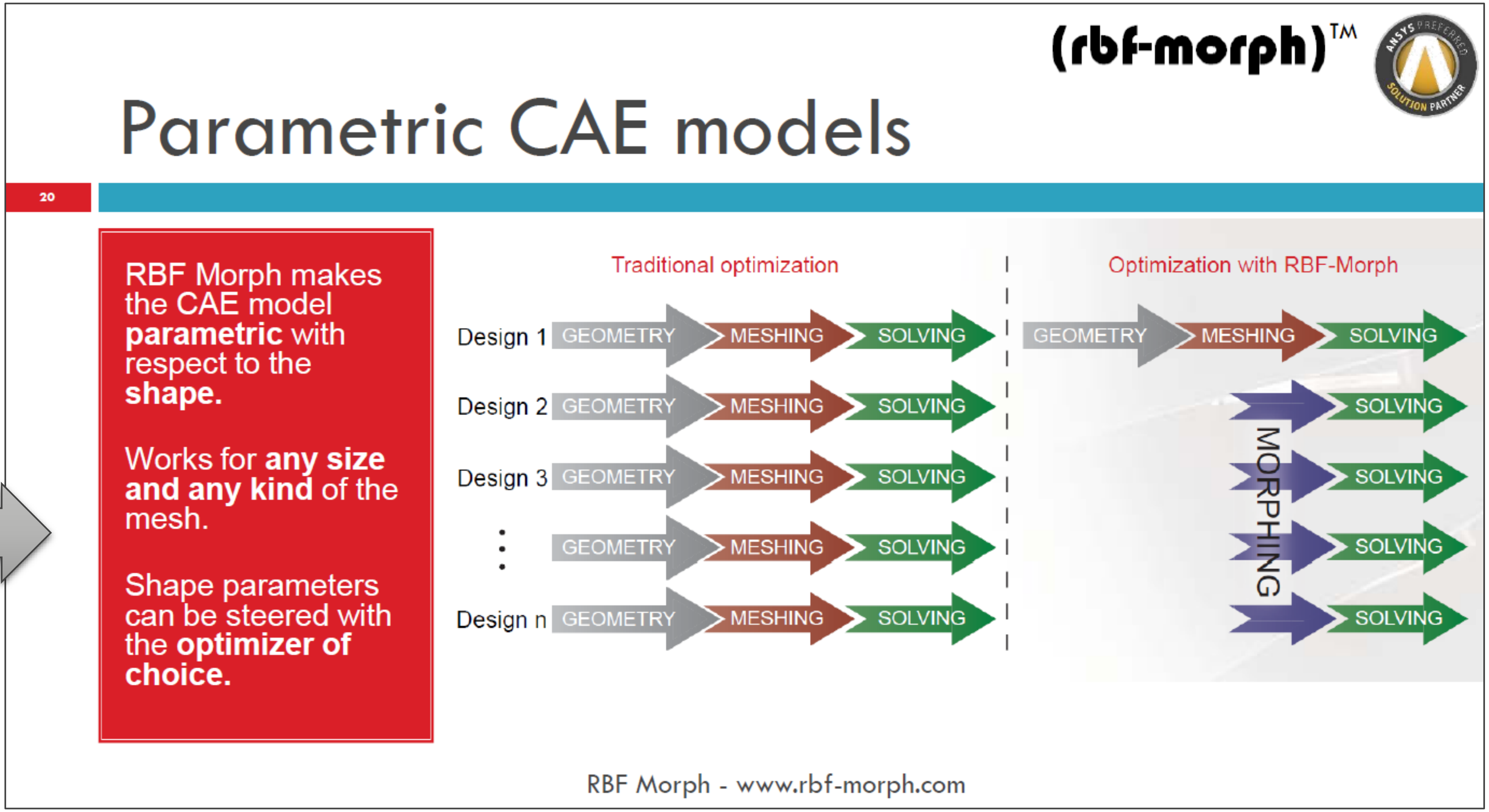






Shape Optimisation within the ALD cycle

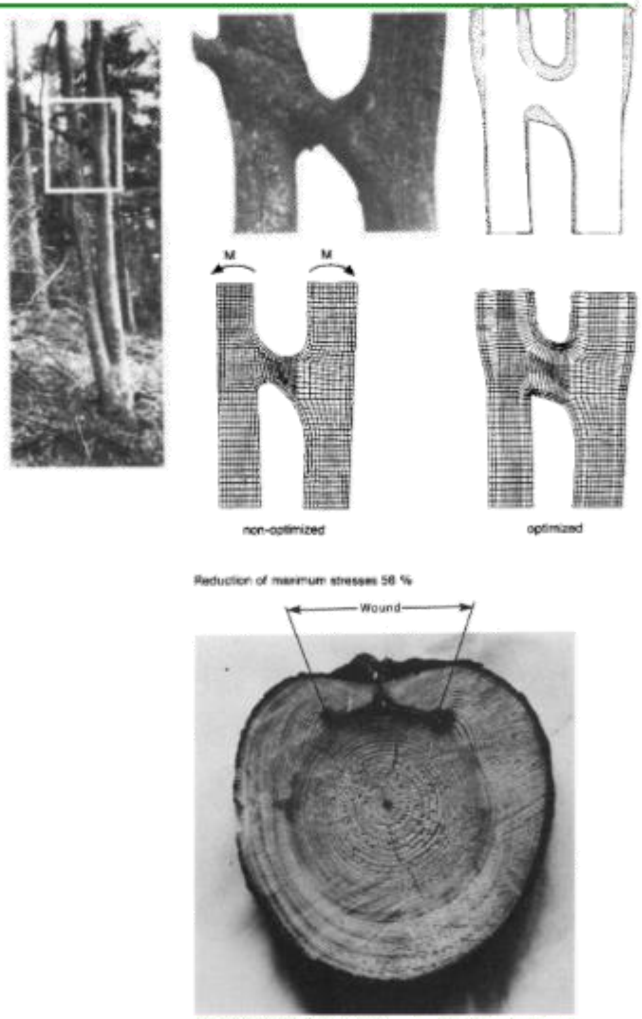




Biological Growth Method (BGM)

BGM Background

- **BGM** approach is based on the observation that **biological** structures growth is driven by **local** level of **stress**.
- Bones and trees' trunks are able to **adapt the shape** to mitigate the stress level due to external loads.
- The process is driven by stress **value at surfaces.** Material can be **added or removed** according to local values.
- Was proposed by Mattheck & Burkhardt in 1990*



*Mattheck C., Burkhardt S., 1990. A new method of structural shape optimization based on biological growth. Int. J. Fatigue 12(3):185-190.

Model set-up for Morphing

- Project*
  - Model (B4)
    - Geometry
    - Materials
    - Virtual Topology
    - Coordinate Systems
    - Connections
    - Mesh
    - Named Selections
    - RBF Morph Set Up
      - RBF Target
        - fixed-faces
        - RBF Source
    - RBF Morph Update
  - Static Structural (B5)
    - Analysis Settings
    - Coupling
    - Force
    - Pressure
    - Frictionless Support
    - Displacement
    - Bolt Pretension
    - Imported Load (A2)
    - Solution (B6)
      - Solution Information
      - Maximum Principal Stress - G1-5_faces - 3. s
      - Maximum Principal Stress - G1-6_faces - 4. s
      - Maximum Principal Stress - A1_faces - 3. s
      - Maximum Principal Stress - B1_faces - 3. s
      - Total Deformation
      - Total Deformation 2
      - Total Deformation 3
      - Total Deformation 4
      - Maximum Principal Stress - Cyl5
      - Maximum Principal Stress - Cyl6

Details of "RBF Morph Set Up"

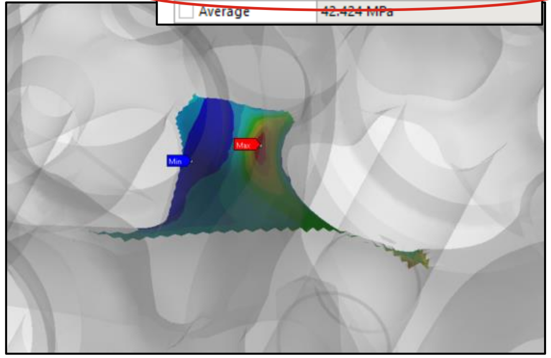
Display	
Show Mesh When Selected	On
General	
Back2CAD Scaling	1
Duplicate Detection	Off
Matrix Precomputation	Off
Optimization	OpenMP
# OpenMP Cores	0
RBF Solver Tolerance	1E-05
RBF Solver Timing	348.9
BGM Mode	Off
BGM Driver ID	1
BGM Driver Name	Static Structural
P Shape ID	30

Details of "RBF Source"

Node Selection	
Scoping Method	Named Selection
Named Selection	sculped_faces
General	
Transformation	Surface Offset
Offset Type	Driven Value
Offset Along	Surface Normal
Auto Offset	On
Approach	Aggressive
N. of Iterations	30
Reference Length	8 mm
Value Type	Max Princ Stress
Threshold Value	1 MPa
Max Surf Offset	0.096 mm
Midside Nodes	Skip
Surface Constraint	No

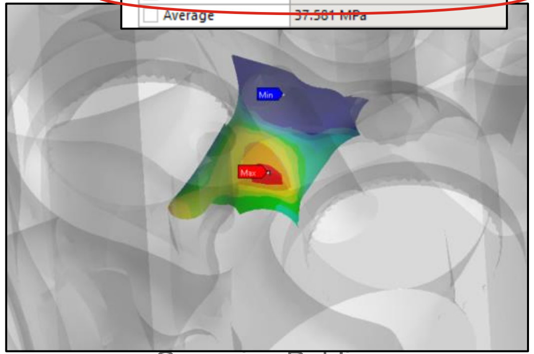
Details of "Maximum Principal Stress - B1_faces - 3. s"

Scope	
Scoping Method	Named Selection
Named Selection	B1_faces
Definition	
Integration Point Results	
Results	
Minimum	-7.2365 MPa
P Maximum	156.74 MPa
Average	42.424 MPa

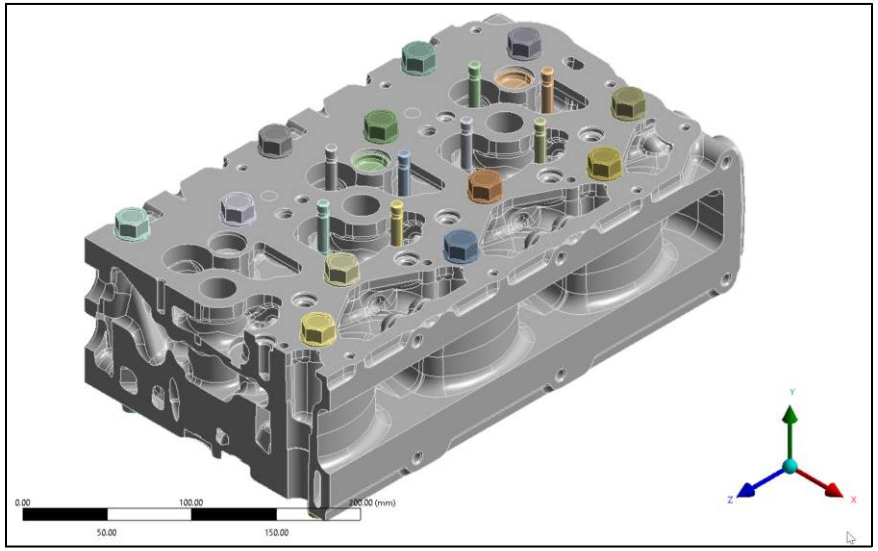


Details of "Maximum Principal Stress - G1-6_faces - 4. s"

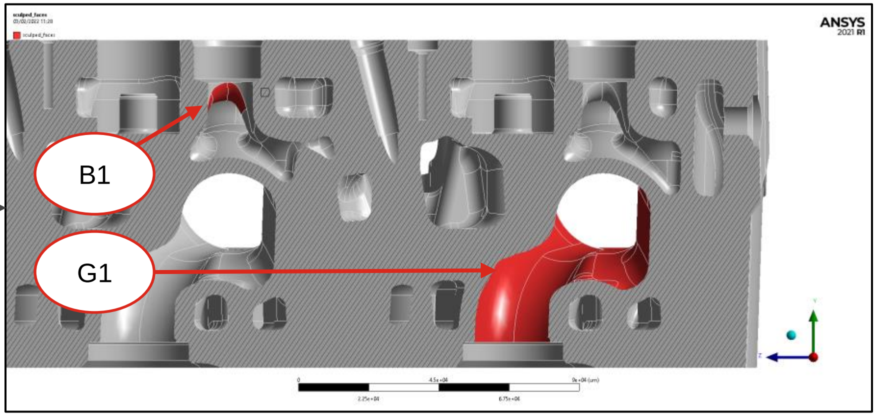
Scope	
Scoping Method	Named Selection
Named Selection	G1-6_faces
Definition	
Integration Point Results	
Results	
Minimum	-17.64 MPa
P Maximum	173.83 MPa
Average	37.581 MPa



Simplified model for fast solution time. Loads considered: A, AP, AT, ATP at cylinders 5 & 6

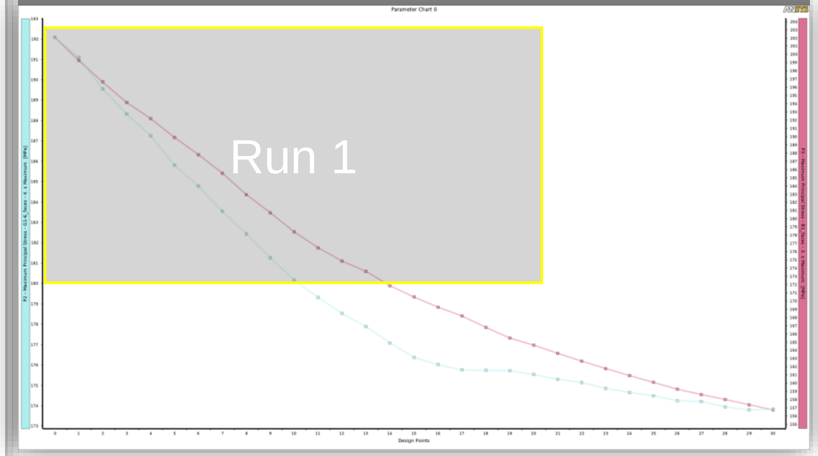


Design regions for B1 and G1 locations (all other faces fixed for morphing)



Shape optimisation at EP6 (G1 location) and UWJ5 (B1 location)

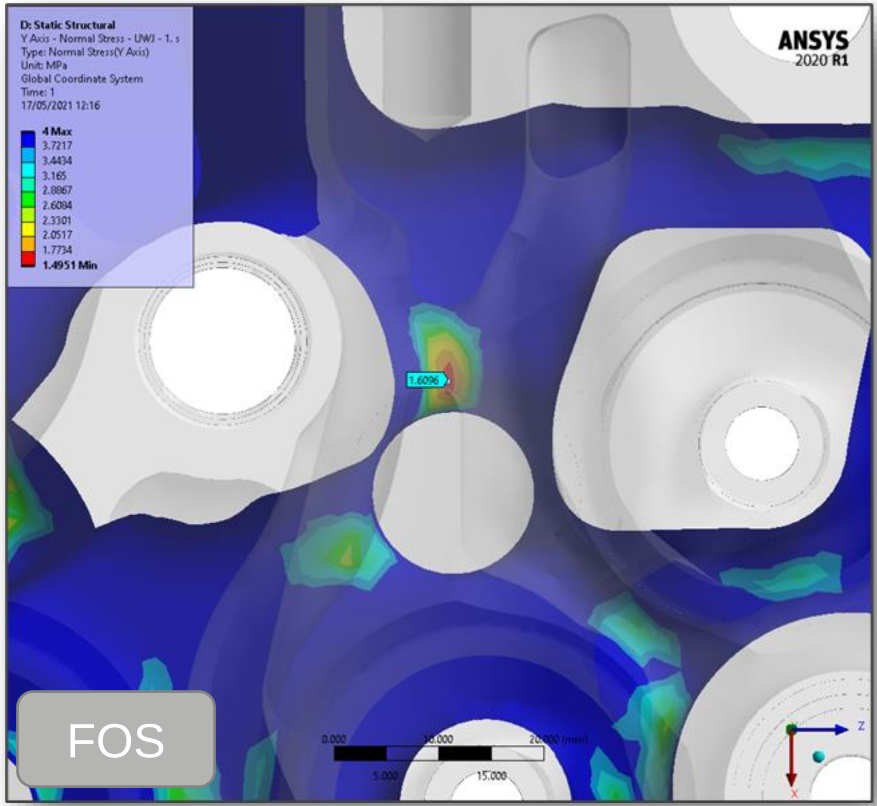
Optimisation method: RBF Morph – Biological Growth Method
Design points: 20
Criteria: Highest maximum principal stress at design regions

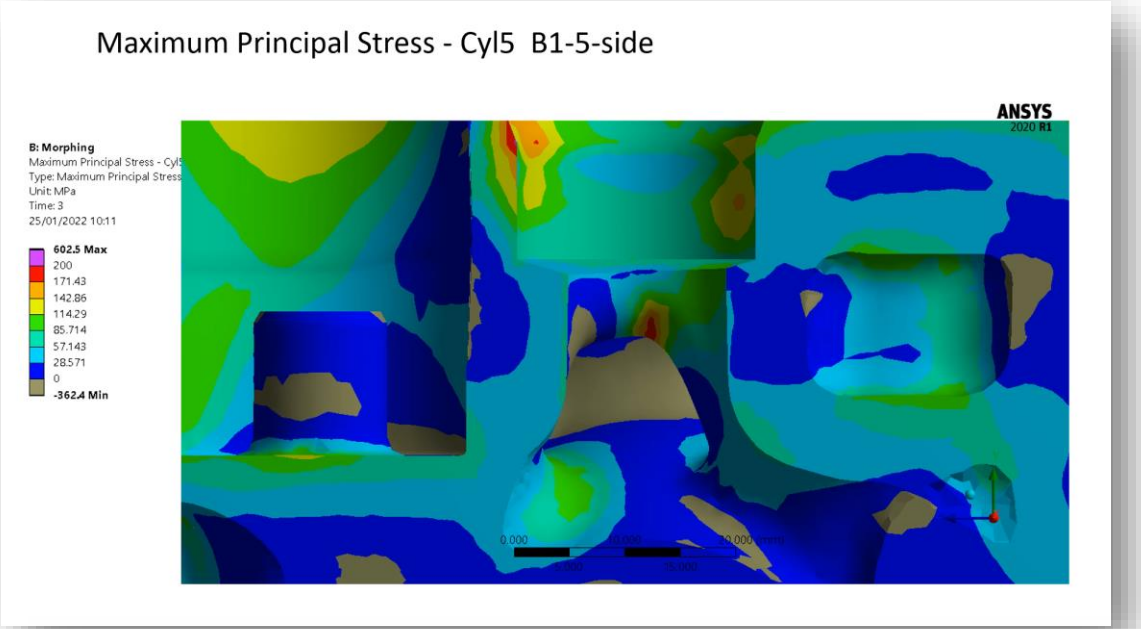


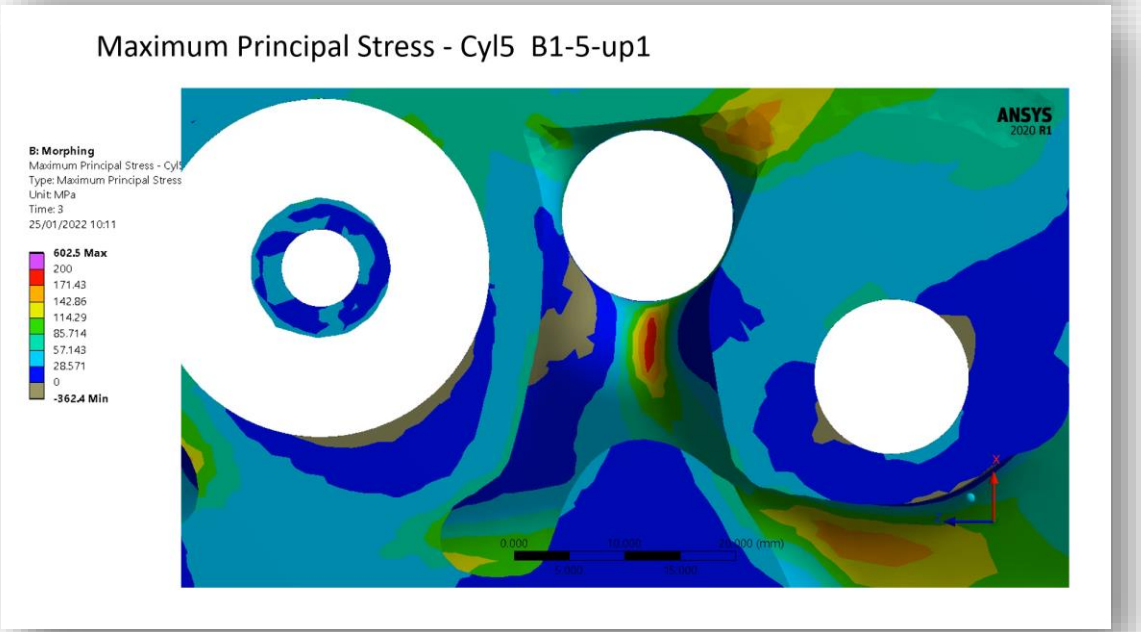
B1 morphing

Design point 0 - Baseline
Max principal stress: 205 MPa
FOS: 1.42

Design point 20
Max principal stress: 175 MPa (-14.6%)
FOS: 1.61 (+13.4%)



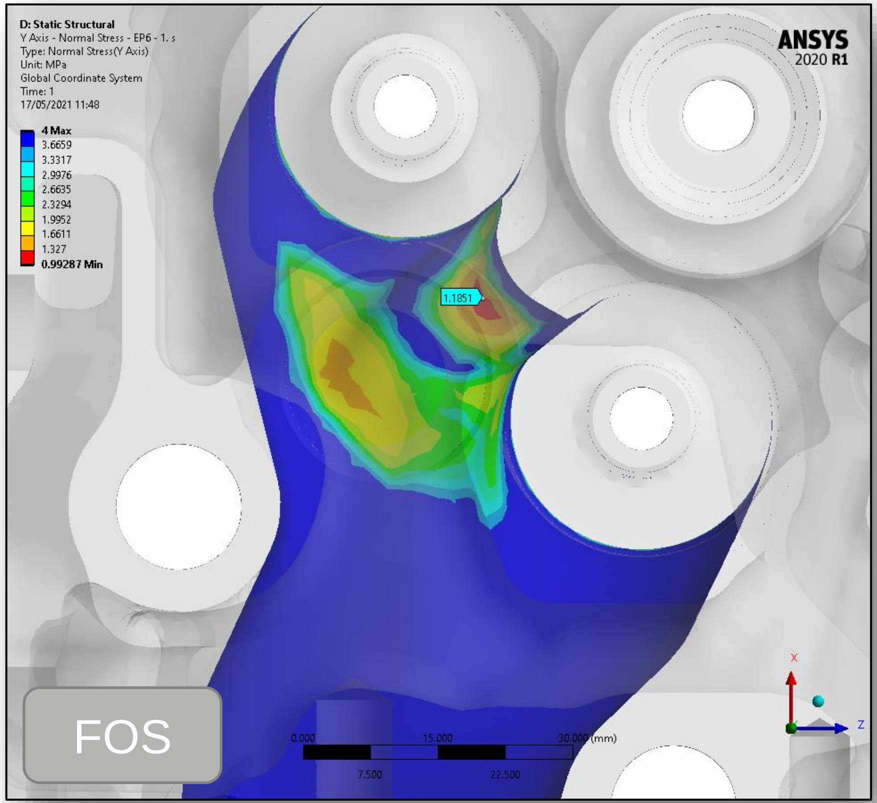


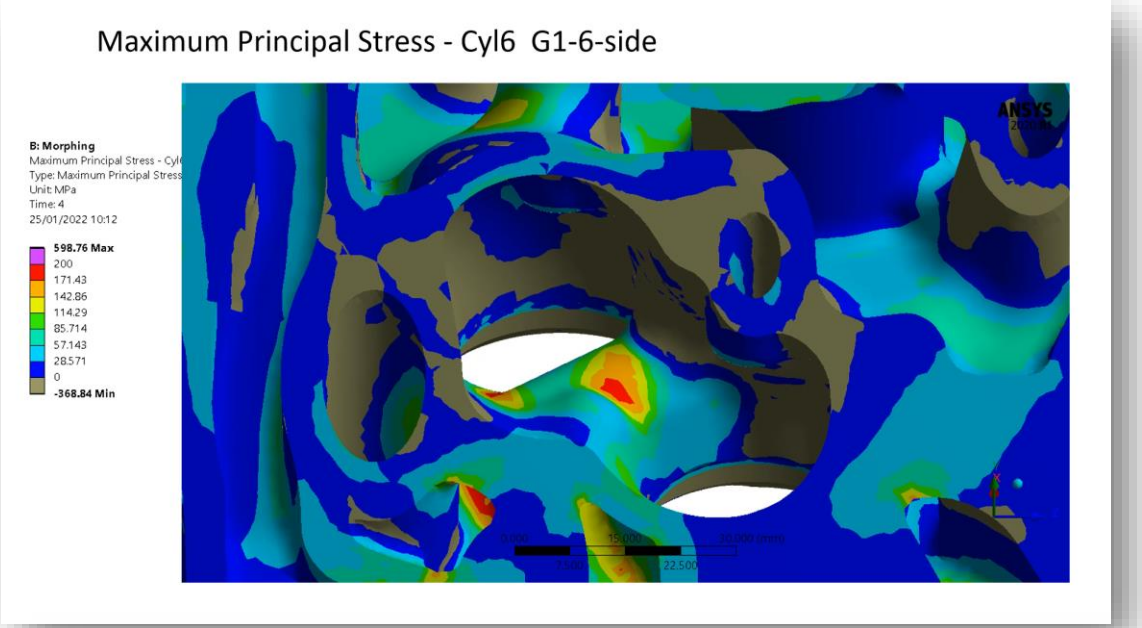


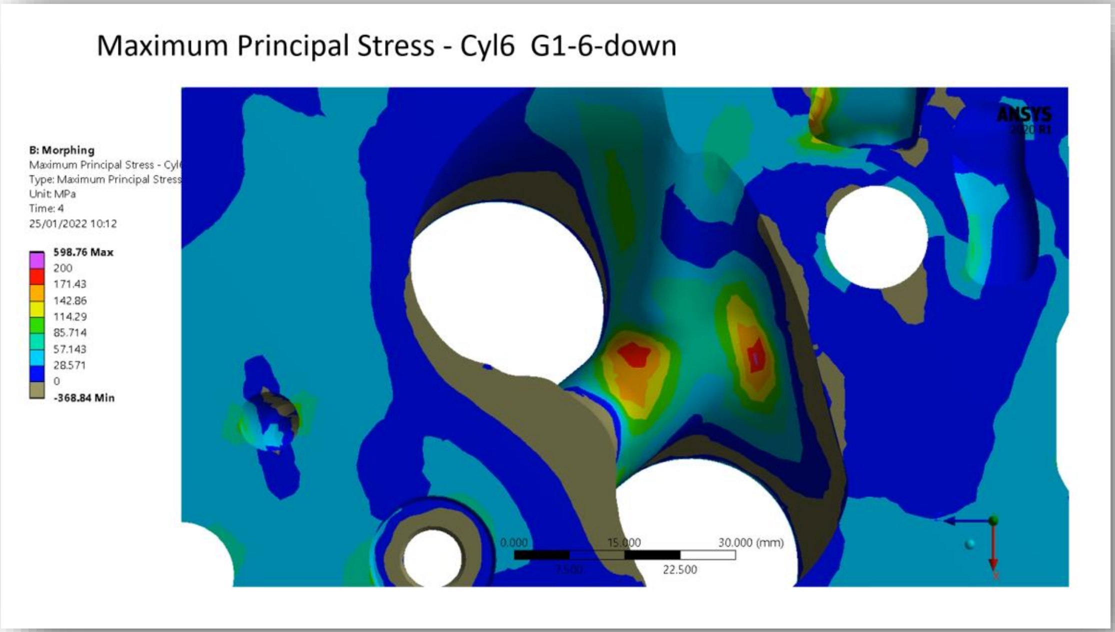
G1 morphing

<u>Design point 0 - Baseline</u>
Max principal stress: 196 MPa
FOS: 1.09

<u>Design point 20</u>
Max principal stress: 180 MPa (-8.1%)
FOS: 1.19 (+9.2%)







Summary

Background:

Static Structural FEA and Fatigue Analysis was carried on a combustion engine cylinder head assembly model

Design and analysis iterations can be time consuming and repetitive

The Challenge:

Iterations typically carried out manually since the complex casting topology makes geometry parametrisation near impossible

The Solution:

- ➢ The RBF Morph - Biological Growth Method allows for effective parameterisation of complex geometry at the mesh level
- ➢ The RBF Morph ACT extension in Ansys Workbench/Mechanical with intuitive user interface

Benefits: better understanding of design change effects and limitations, clear design recommendations through exportable 3D model visualisation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