Thermal Mechanical Fatigue
in heavy duty diesel engines

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DAF Central Laboratory

Content

- Engineering relevance for modelling
- Thermal Mechanical Fatigue in heavy duty trucks
- Multi scale modelling (FOM/IPP Physics of Failure project)
- Strain range partitioning method

UNIVERSITEIT GENT

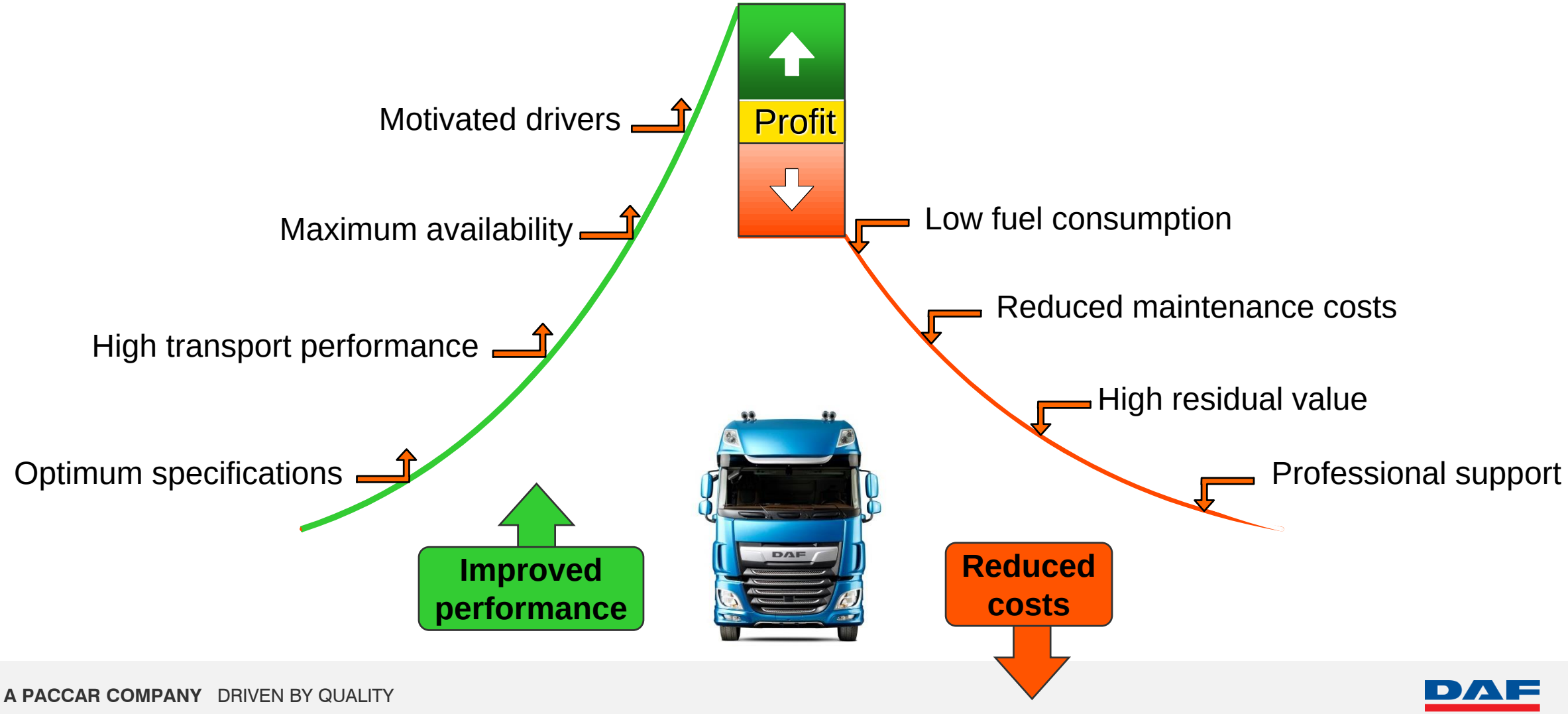
TU/e

TU Delft

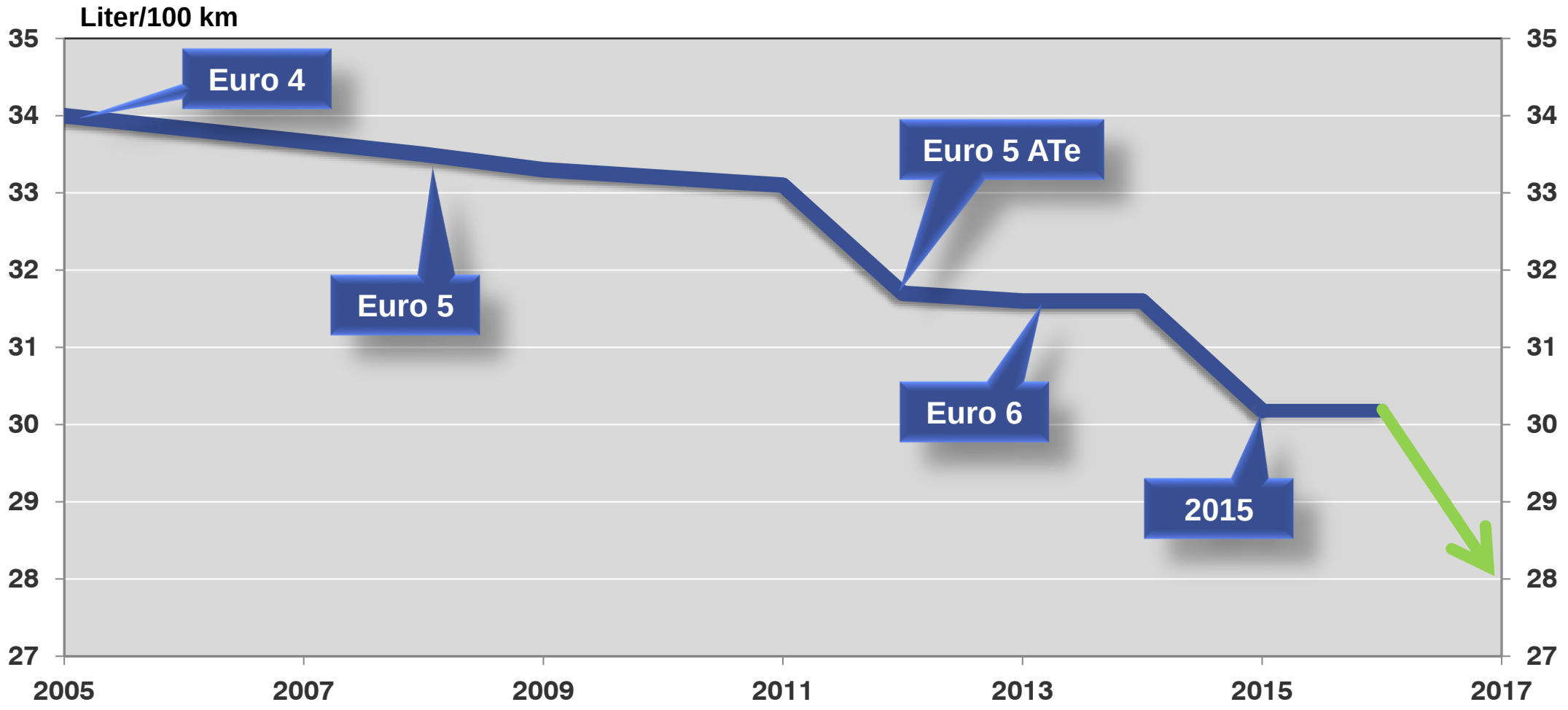
DAF ‘A PACCAR COMPANY’

A PACCAR COMPANY

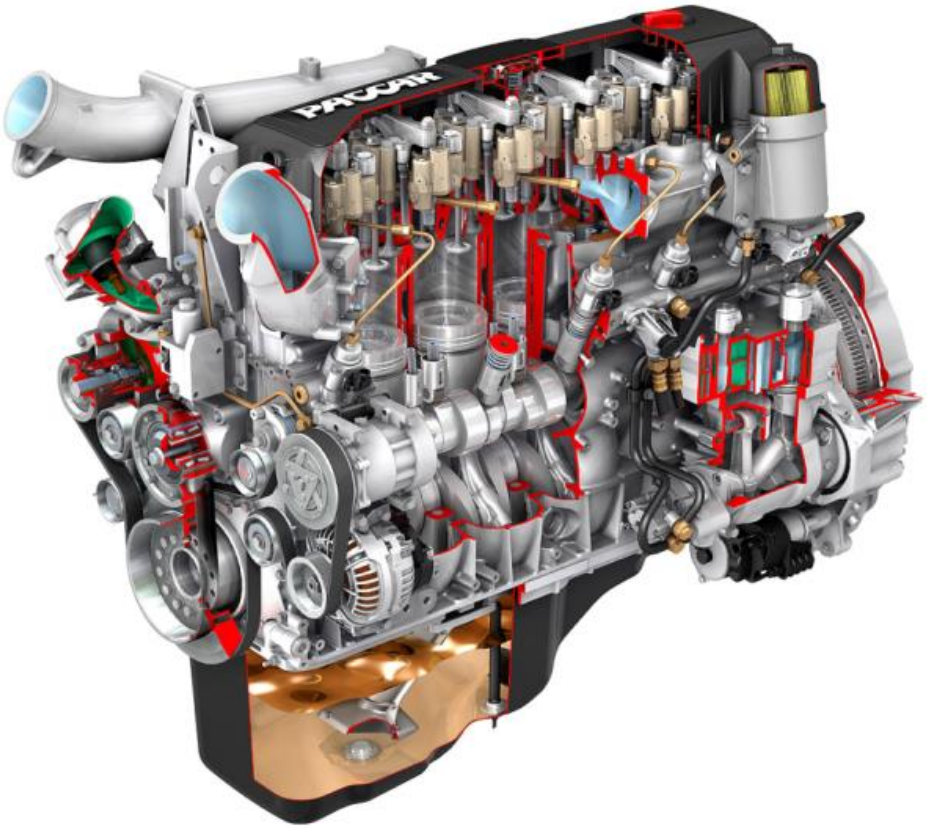
MARKET **REQUIREMENTS**

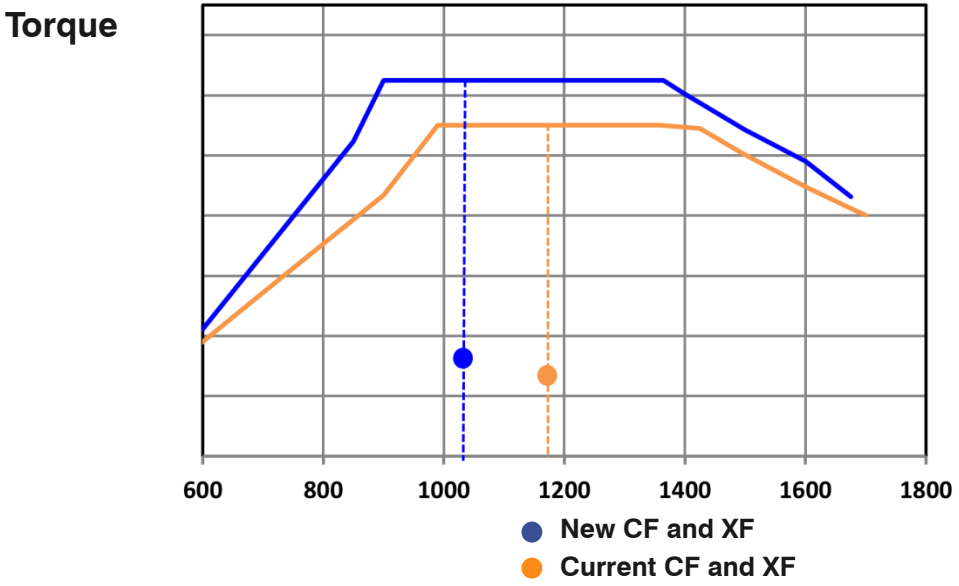


LARGEST **FUEL ECONOMY IMPROVEMENT** EVER



DOWNSPEEDING & MULTI-TORQUE



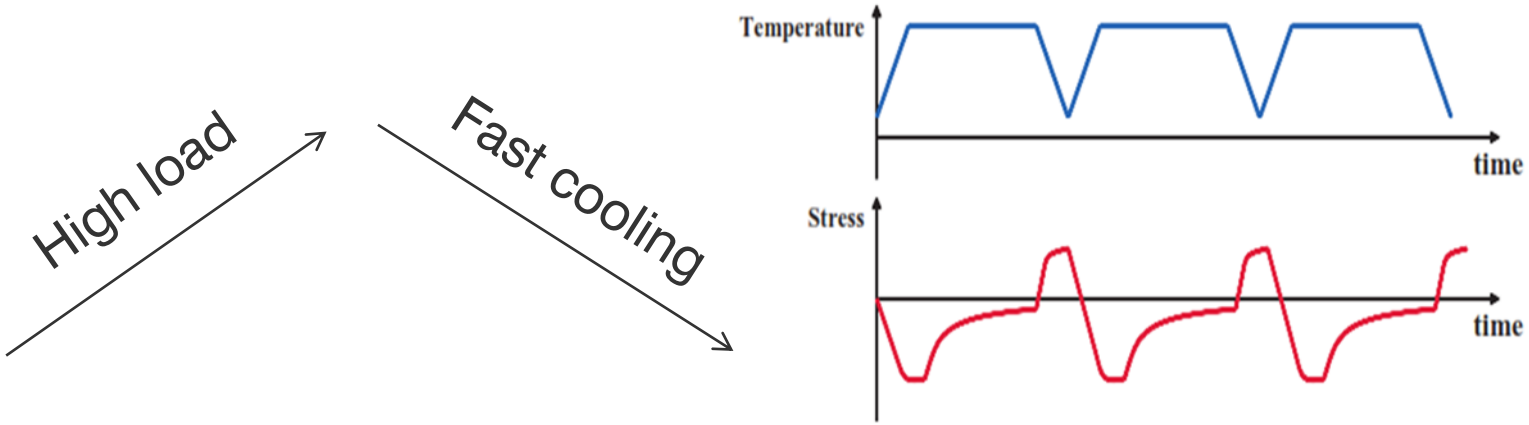


- Improved efficiency
  - Less rpm at cruising speed
- Increased torque
  - Drivability
  - Gradeability

TMF in heavy duty trucks

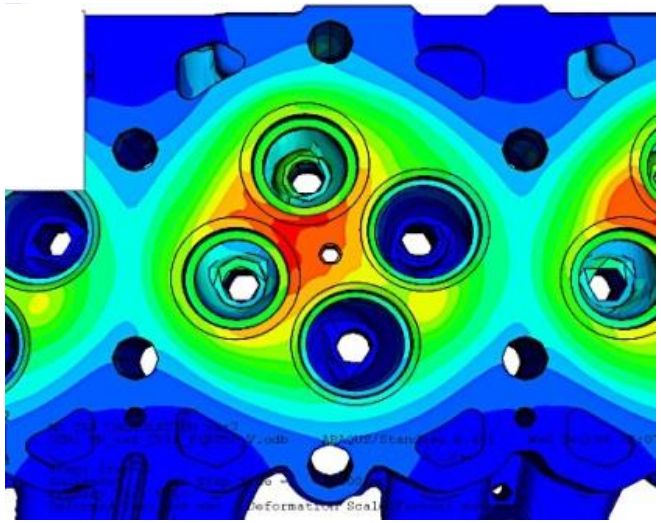
Gotthardpass, biebchessbiker.blogspot.nl

Ford 1163hp turbo six engine dyno, Source Youtube



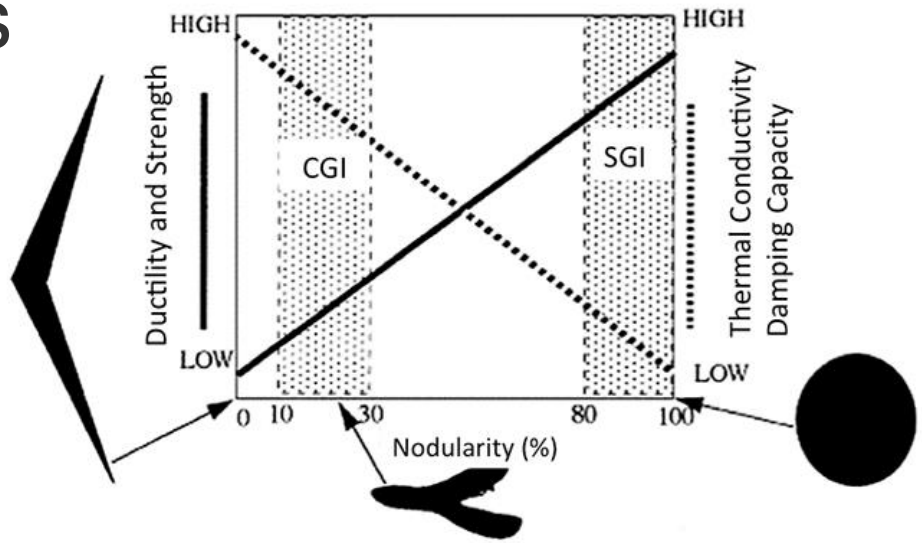
- Cylinder head
- Exhaust manifold
- Turbo
- Exhaust pipes
- After treatment system
- EGR cooler

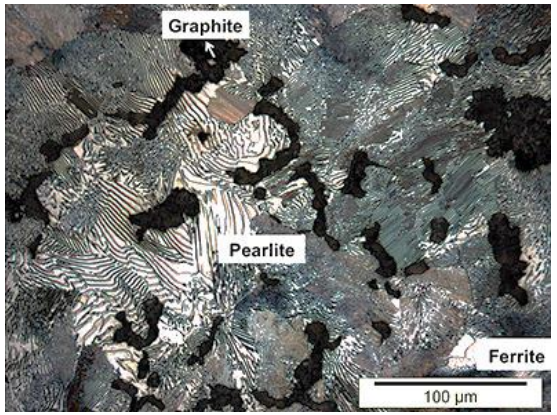
Materials used for cylinder heads



Compacted Graphite Iron

PACCAR was the first engine manufacturer to utilize CGI in both the block and cylinder head of a heavy-duty diesel engine. With shorter and thicker graphite particles than standard gray iron, CGI offers stronger adhesion between the graphite and the iron giving this material in the MX-11 engine greater tensile strength and excellent thermal resistance.



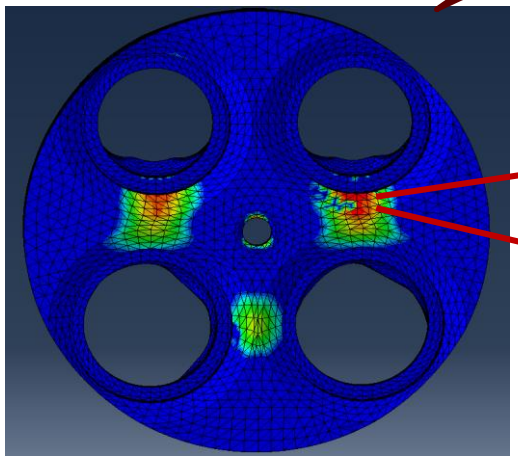


Reliable quantitative assessment of durability prior to physical testing requires highly sophisticated simulation solution

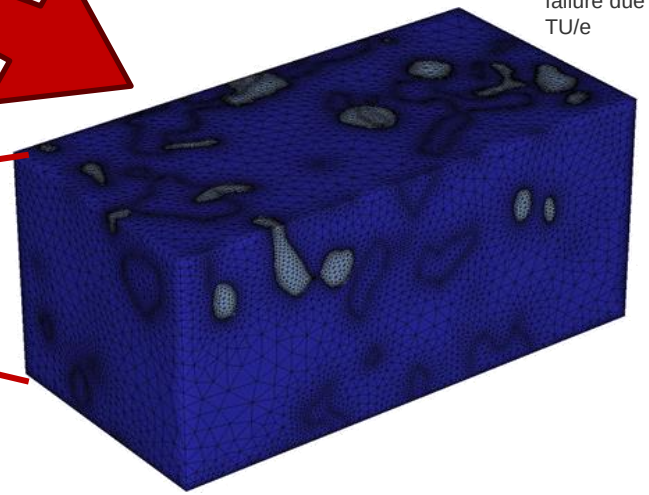
Multi scale modelling of thermal mechanical fatigue

R.v.Ravenstein, “Software validation for crack initiation on high and low cycle fatigue and thermal mechanical fatigue”, DAF/TU/e

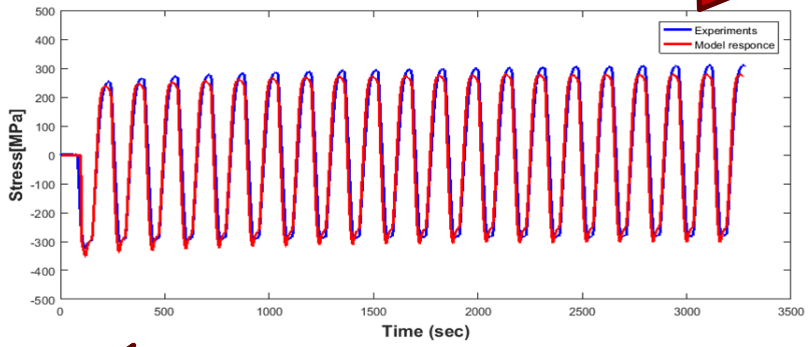
$\boldsymbol{F}_{\mathrm{M}}, T$



A. Mohammadpour, “Multi-scale physical modelling of failure due to Thermo-Mechanical Fatigue in cast iron”, TU/e



$\boldsymbol{\sigma}_M, \overline{\varepsilon^p}$



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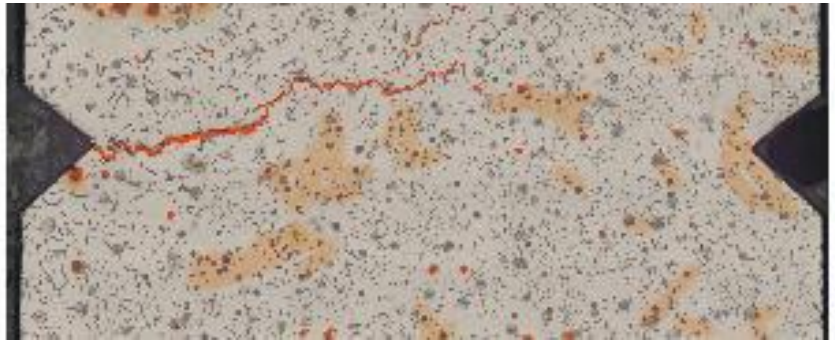
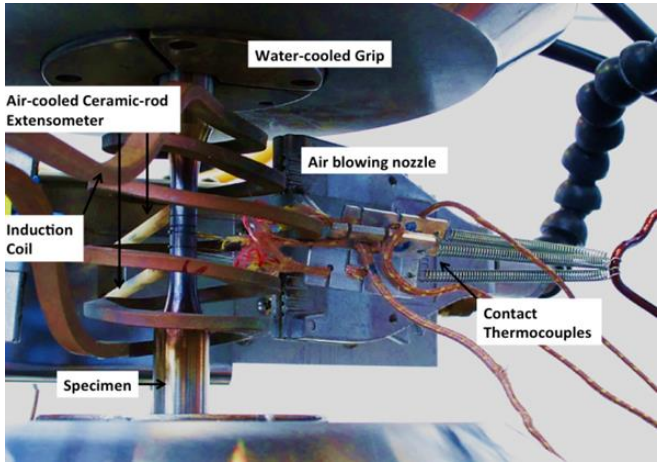


TMF testing



Hysteresis loop during testing

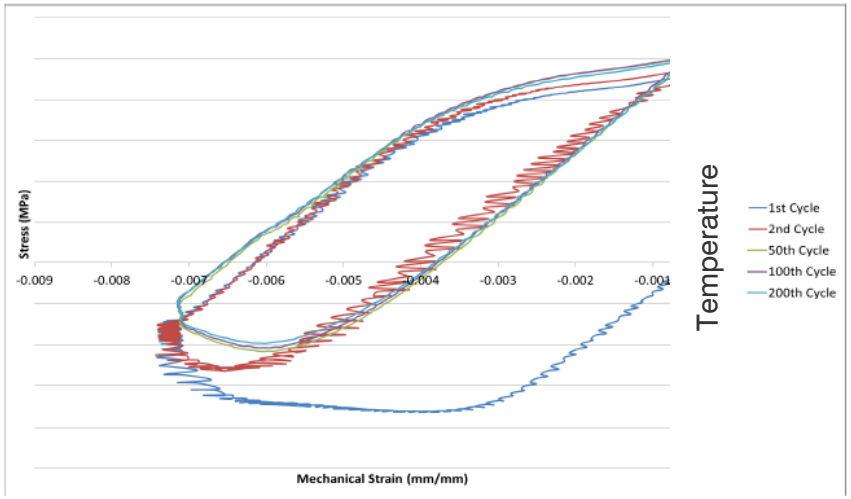
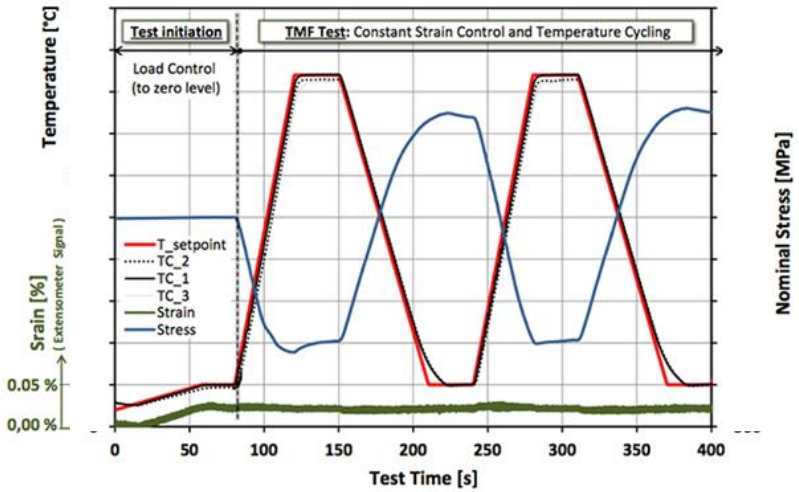
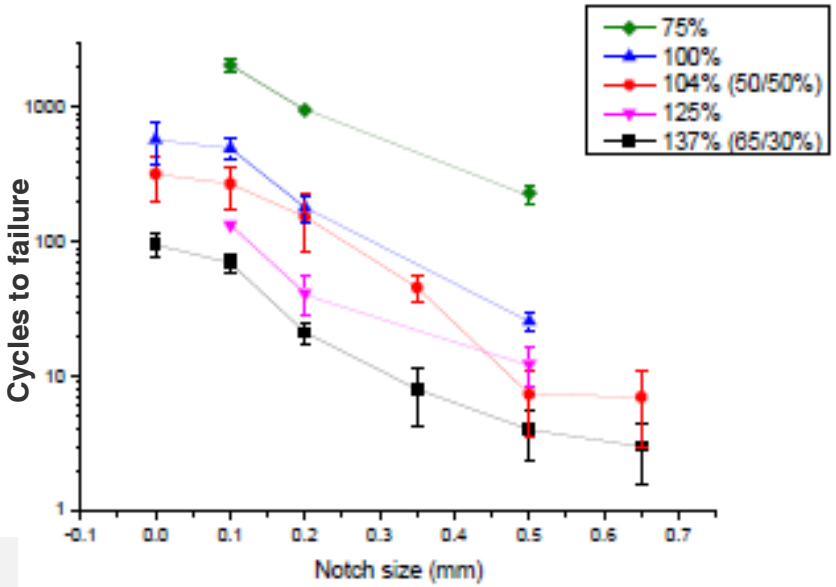
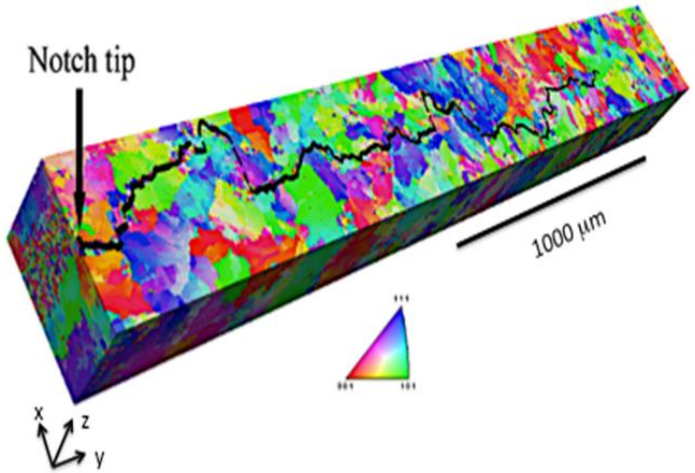


Figure D.3: Constraint = 100 %, smooth sample, N_{10} = 239.



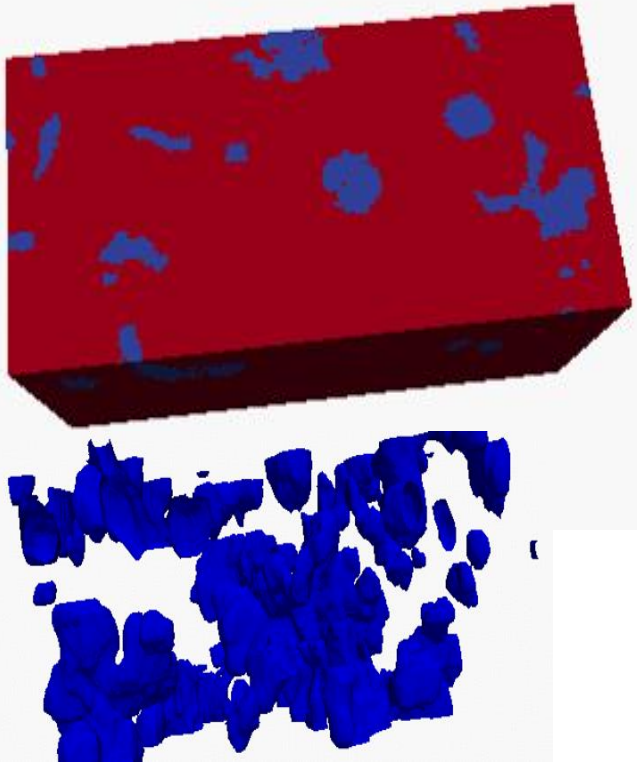


Voxel based **3D microstructural model of CGI**



500 x 250 x 250 μm

matrix & graphite



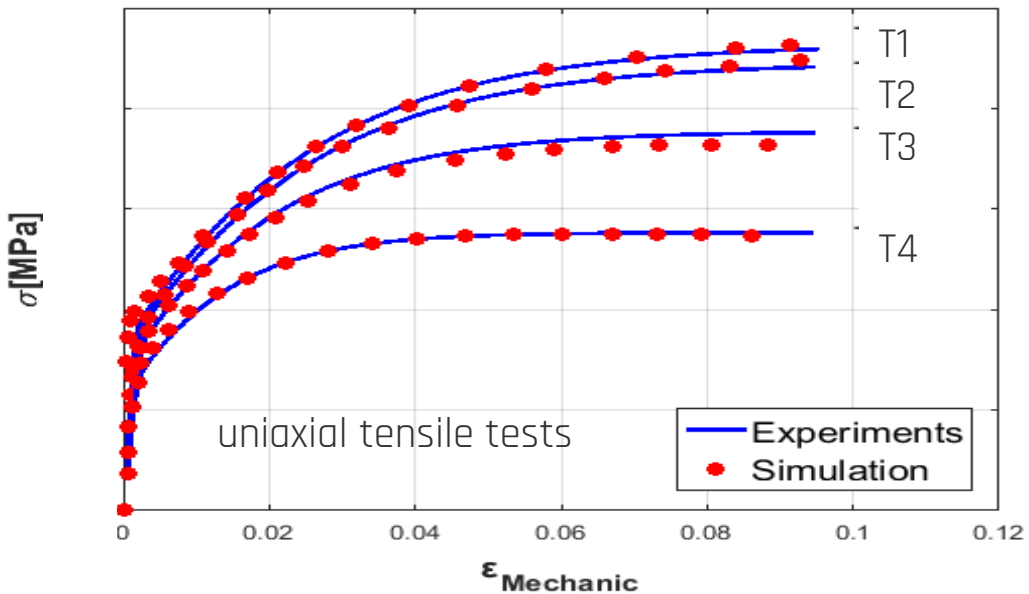
graphite only

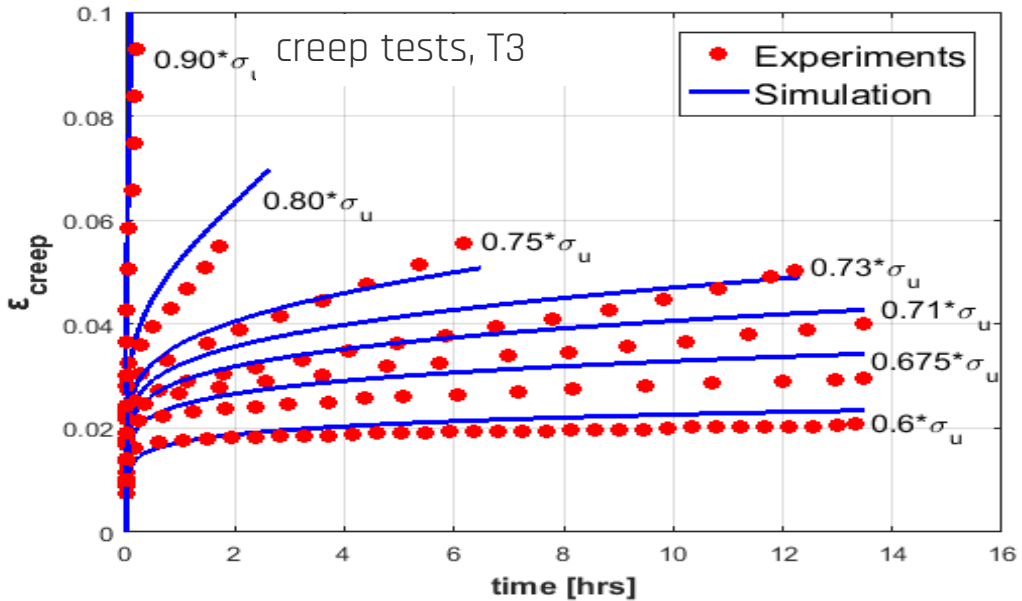
Work in progress:

- from voxel based microstructure description to analytical surface description
- better geometry description
- better quality FE mesh
- Perlite model
- Graphite model
- Interface model perlite/graphite

Material model for pearlite matrix

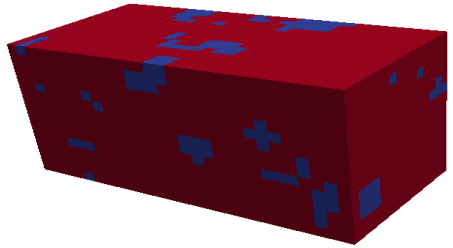
- Developed, implemented and calibrated on measurements on pearlitic steel (similar to matrix composition in CGI)
- Model includes:
  - Temperature dependence
  - Time dependence
  - Plasticity, inelastic strains
  - Creep
  - Stress relaxation

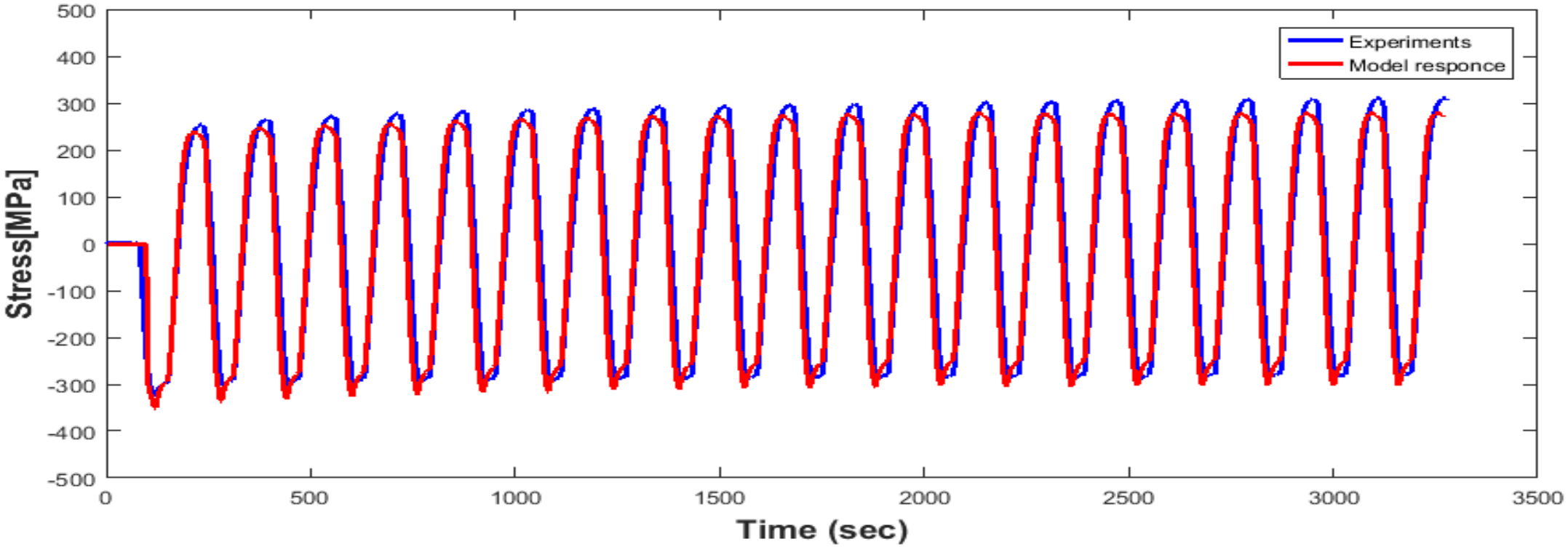




Simulations of thermal cycling test

- Preliminary results on simplified microstructural model
  - Uniaxial test
  - Thermal cycling
  - Full constraint conditions
  - Experimental data: TUDelft



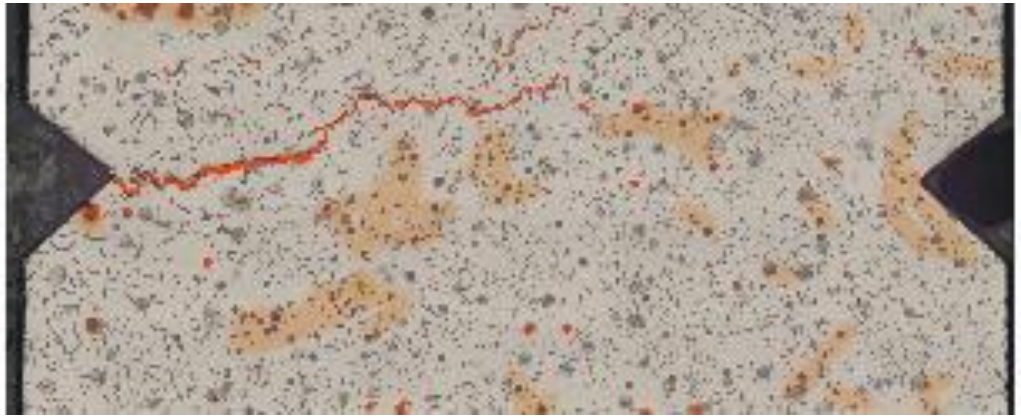


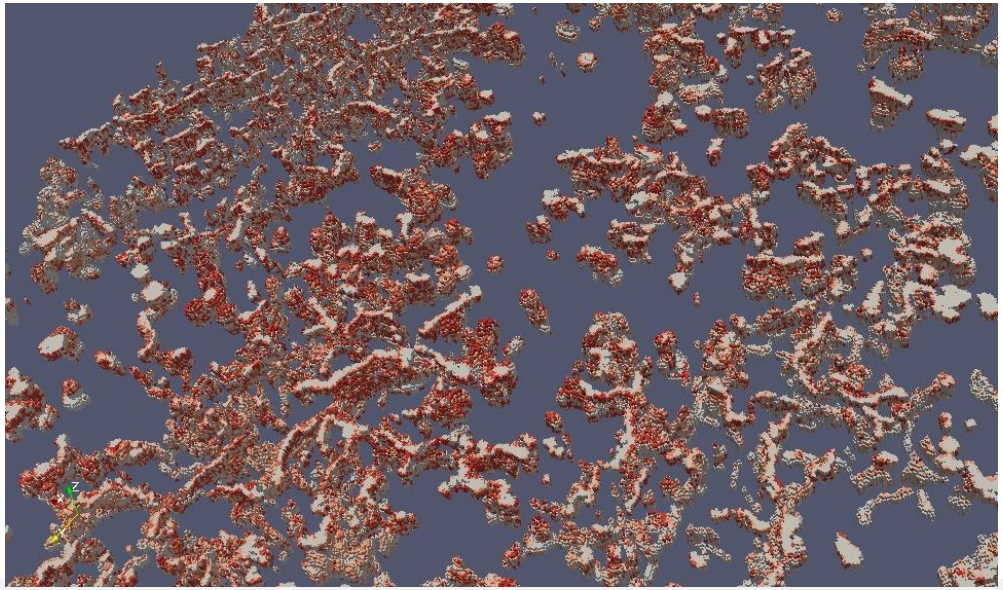
Current work

- Crack initiation
  Graphite debonding = crack initiation
  Detectable crack (MPI) >1mm

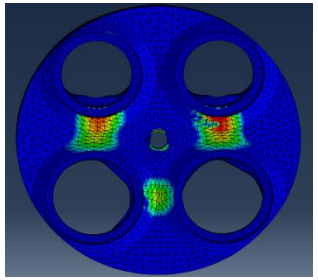
- Crack growth
  Paris Law can predict crack length, not crack path

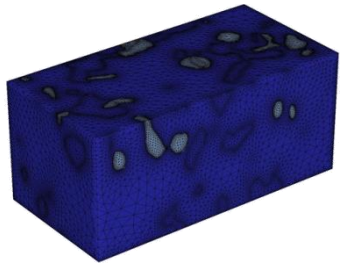
- Interface bonding

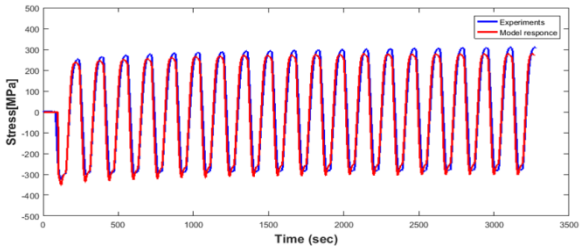




Integration M2i - POF at DAF PD Engines





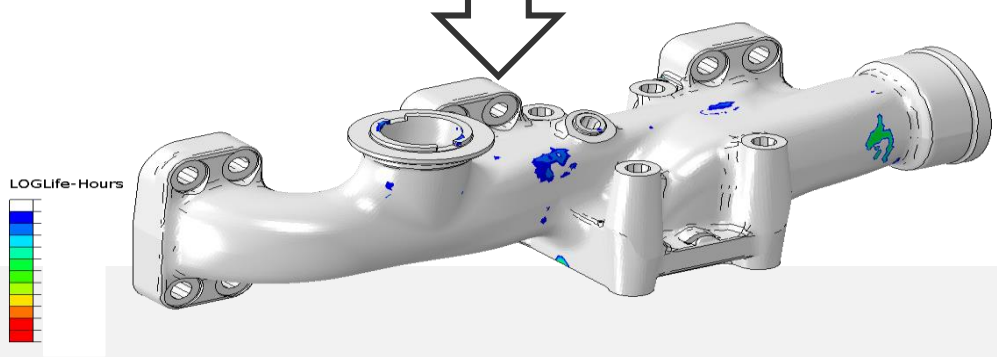


Workflow

FEA Cylinder Head Firedeck , output: stress range from FEA at hotspot

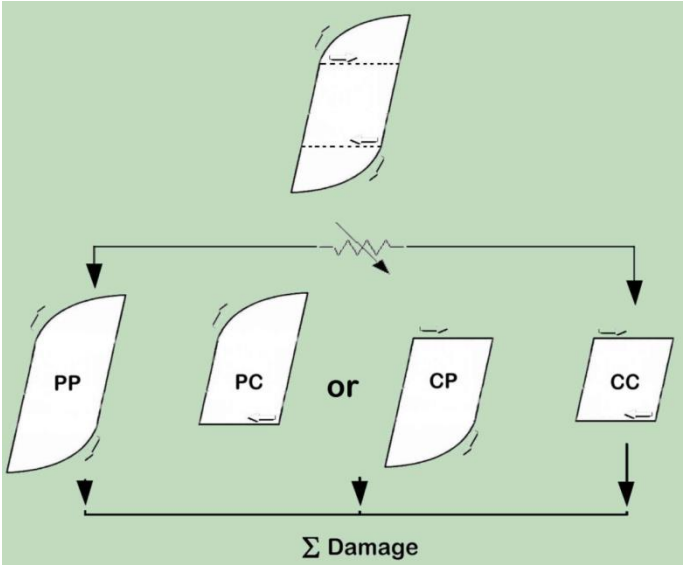
Unit Cell representation CGI 450, output : damage calculation in multiscale model

Life Prediction for complete model

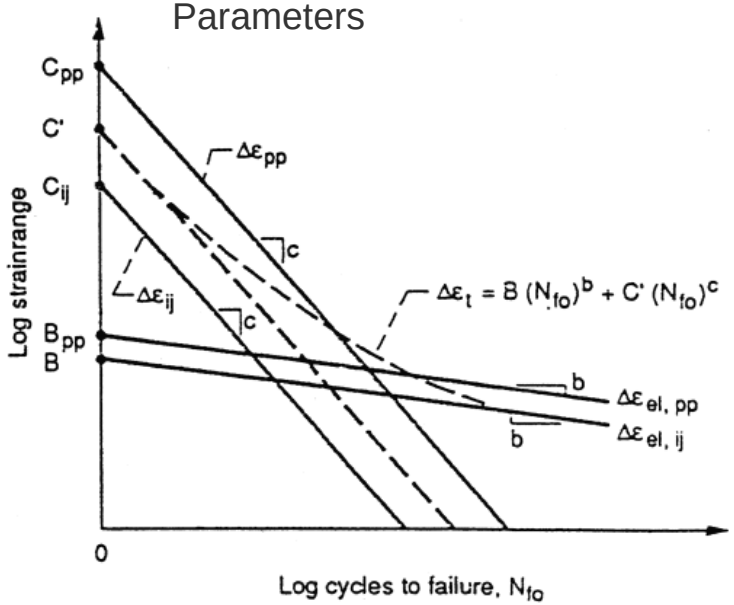


Strain range partitioning

- Fatigue/creep interaction in bulk material
- Life time prediction based on Coffin Manson with creep component (PP + PC),
- Developed by Nasa 1974



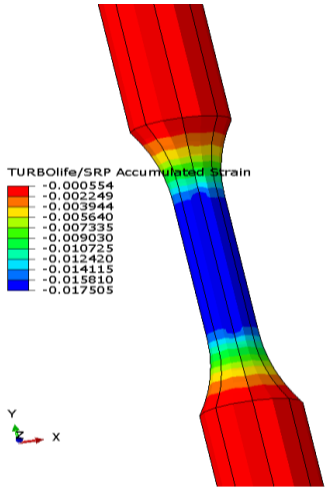
LCF Coffin – Manson Parameters



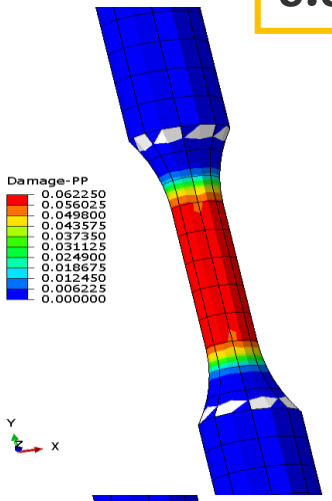
HCF Basquin Parameters

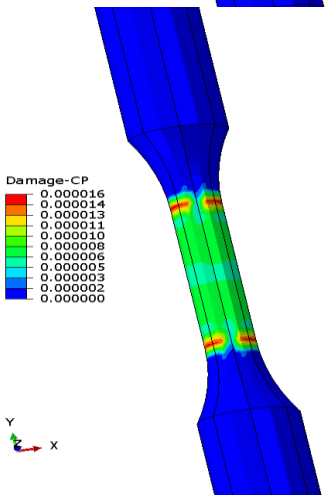
SRP verification

Total acc. strain : -0.0175



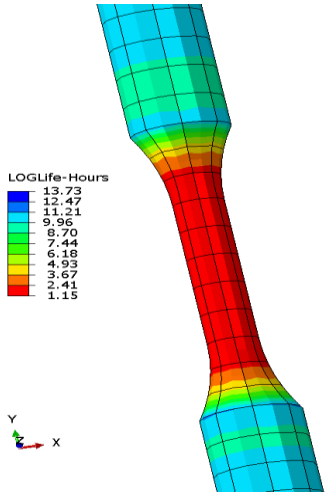
Damage PP: 0.0589





Damage PC: 5.5^{E}-6

Minimum Life=14.7 hrs = 157 cycles



fe-safe/TURBOlife

Conclusions

- Accurate prediction of durability of Thermal mechanical fatigue loaded components requires highly sophisticated simulation solution
- Multi Scale model shows good results w.r.t. mechanical response, damage model in development
- The constitutive material models can be implemented in standard simulation software to improve the current live time predictions
- SRP approach better describes creep-fatigue interaction, though is a bulk approach and does not take microstructural influences into account

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