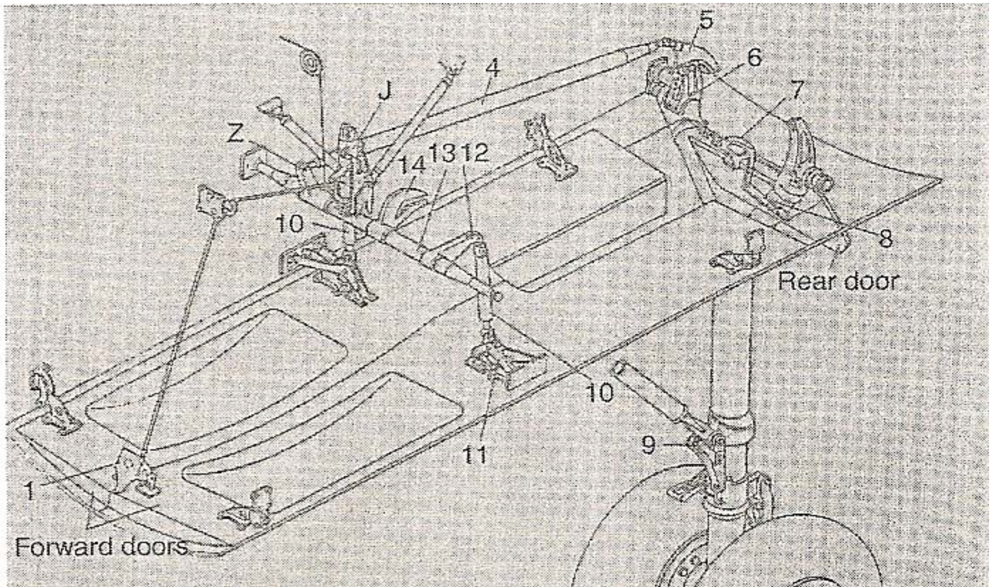
NA Regional Summit 2008 NAFEMS
2020 Vision of Engineering Analysis and Simulation
October 29 - 31, 2008 | Hampton, Virginia

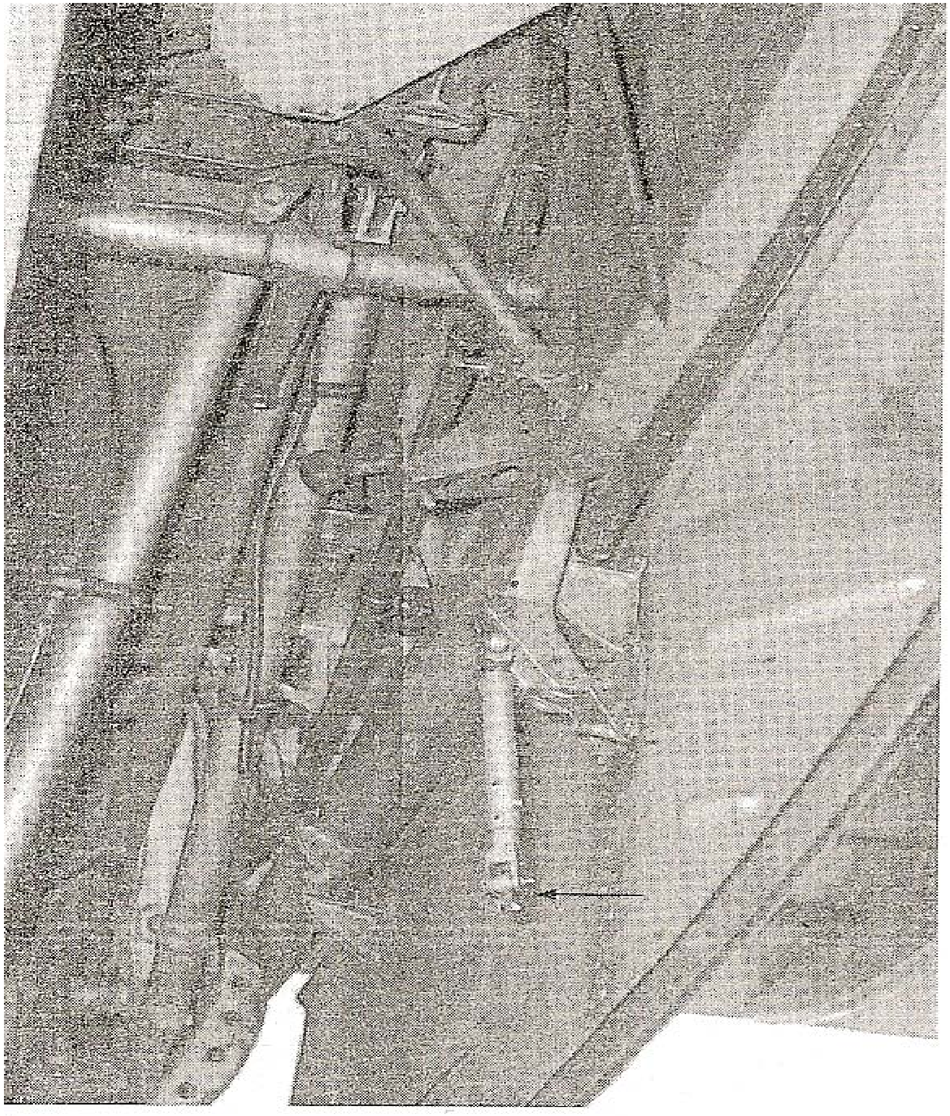
Fatigue & Fracture Analysis "On the Fly"

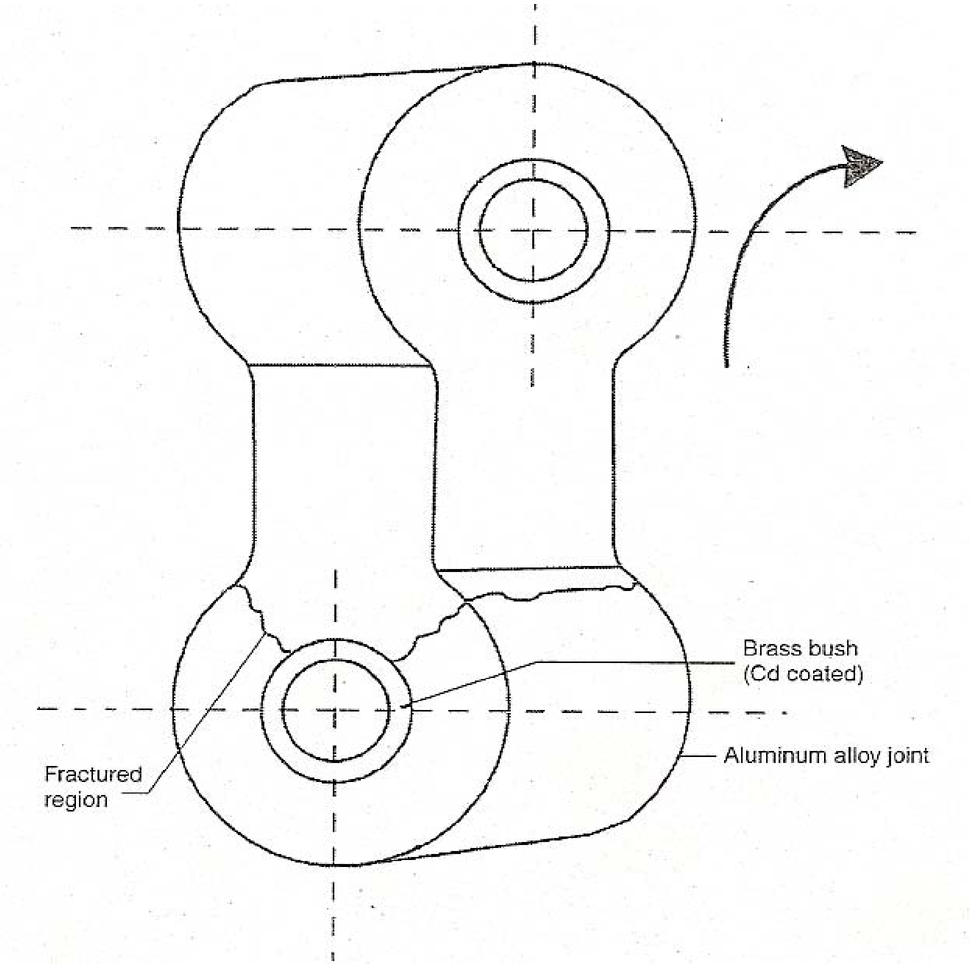
Edward F. Punch
Punch Software Solutions

Telephone call. It is for you…..

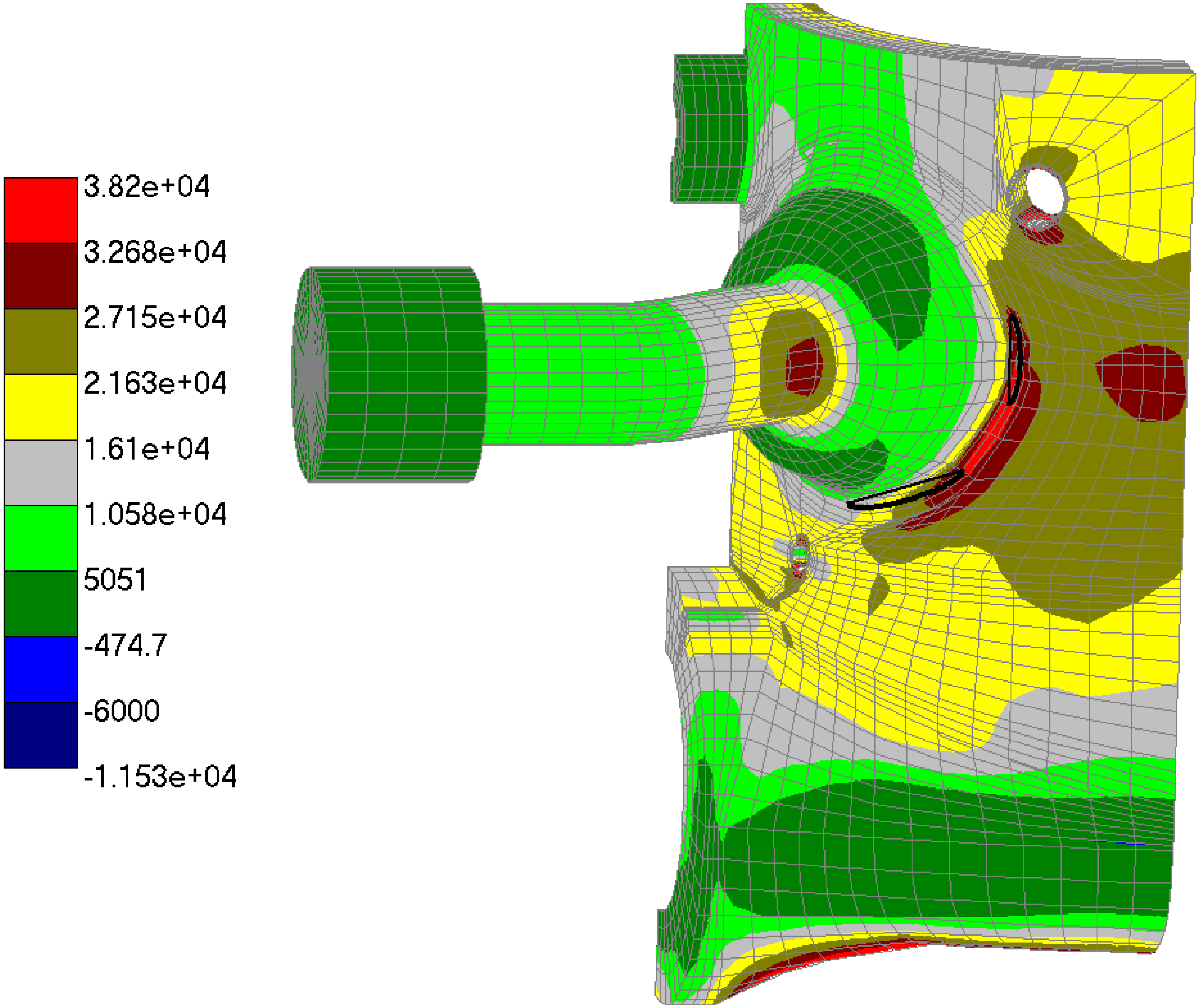


1. Door mechanical lock
2. Bellcrank
3. Up-lock
4. Longitudeinal rod
5. Link
6. Mechanism drive lever
7. Bracket
8. Rod
9. Mechanism drive lever
10. Rod with forked universal joint
11. Lock for opening door on ground
12. Lever
13. Mechanism shaft
14. Link




Brass bush
(Cd coated)
Aluminum alloy joint
Fractured
region

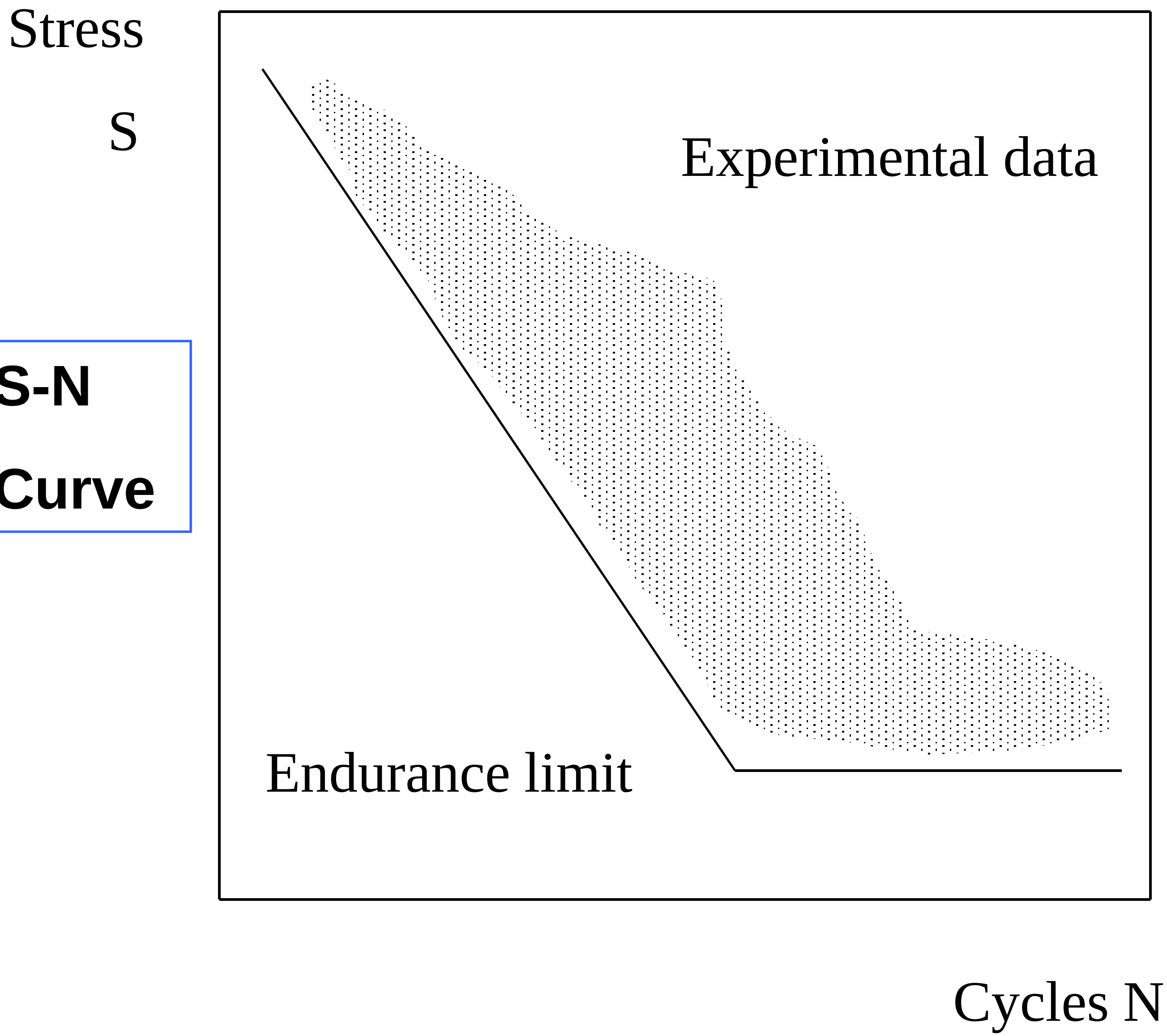
FEA + Superposition

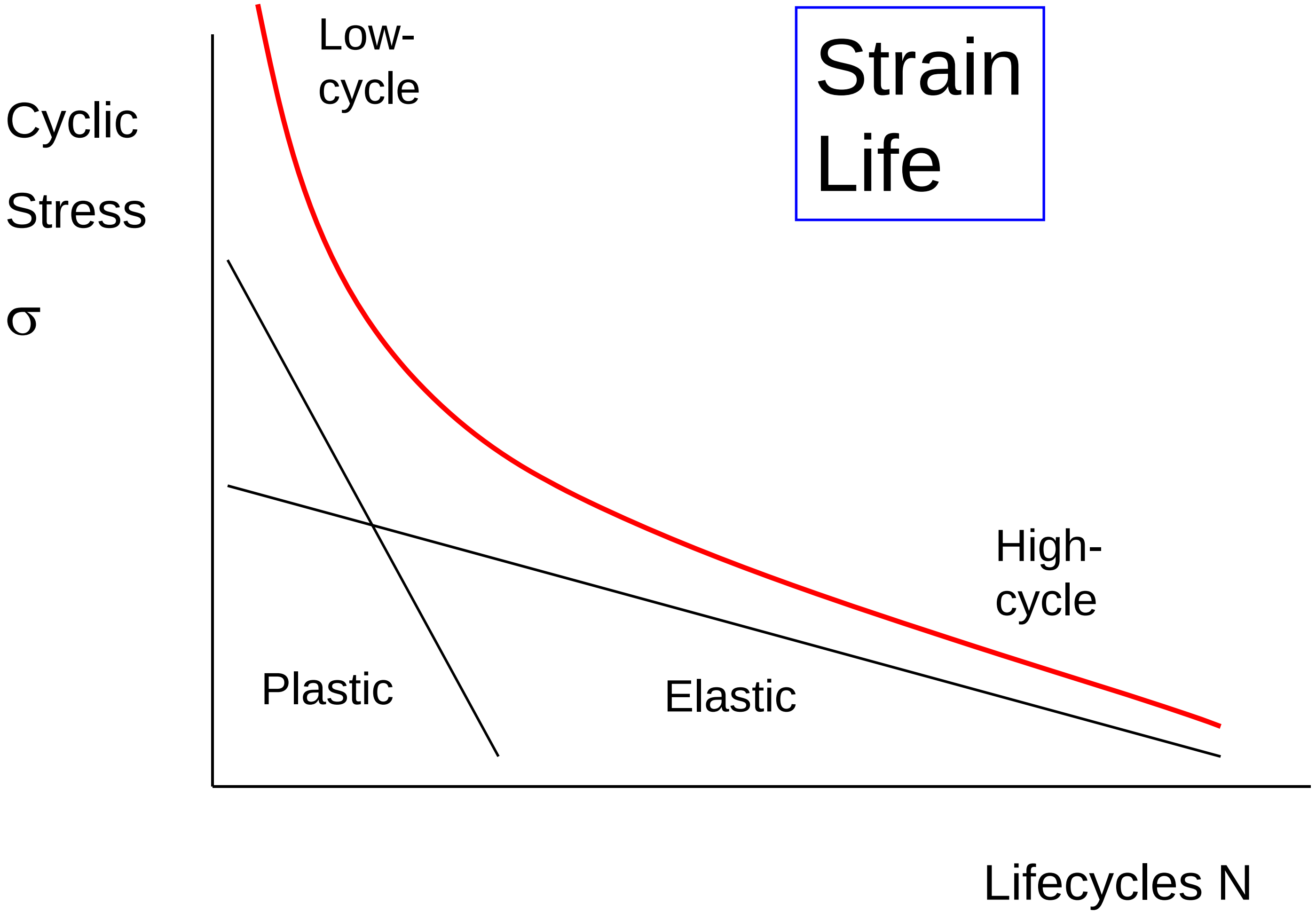


Fatigue design methods:

- Wohler S-N curve (stress proxy)
- Strain-life approach (strain proxy)
- Continuum damage theory
- Fracture mechanics

S-N Curve




Low-
cycle
Strain
Life
Cyclic
Stress
σ
High-
cycle
Plastic
Elastic
Lifecycles N

Drawbacks of Strain-life

- Crack is not modeled
- Low-cycle fatigue only
- Difficult to fit experimental data
- Specific to residual stress & surface treatments
- “Push-button” strains are computed from coarse tetrahedral FE meshes → Failures

Continuum damage theory vs. elasto-plasticity

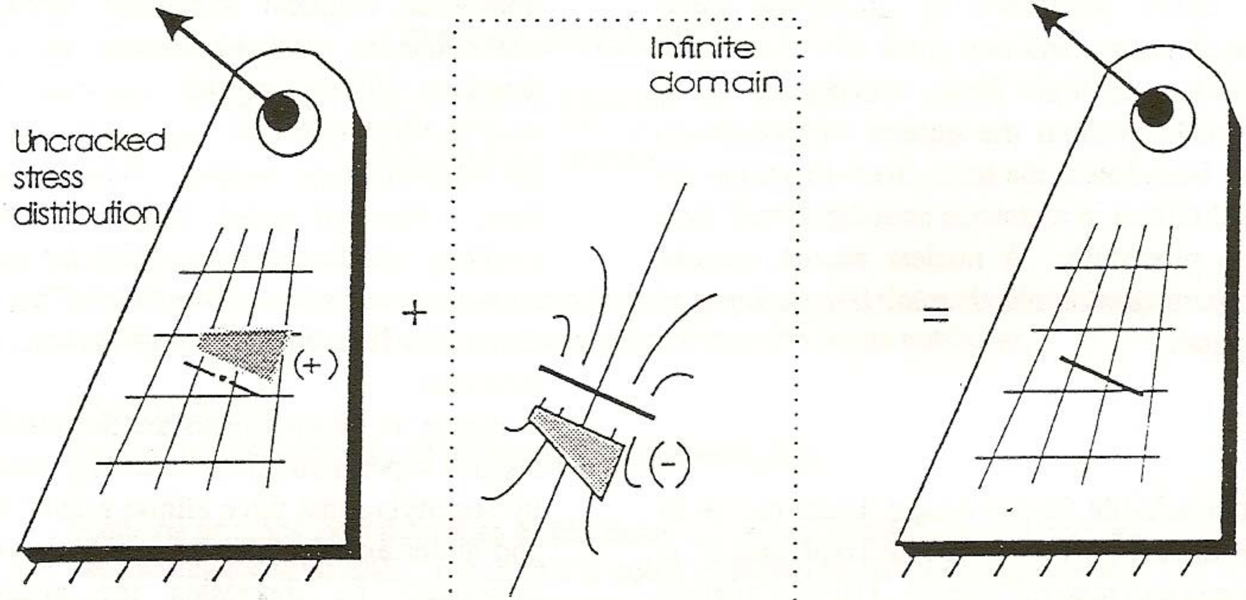
- Elastic modulus
- Poisson ratio
- Yield stress
- Ultimate stress
- Critical damage D_c
- Asympt. fatigue σ_f
- S & s → Dissipative potential function

- Elastic modulus
- Poisson ratio
- Yield stress
- Ultimate stress

Fracture mechanics approaches

- Model *the crack and crack growth*
- Use tables of standard K-factors (e.g. NASCRAC)
- Mesh the crack front (e.g. ABAQUS)
- Superimpose cracks on *existing* finite element meshes → Alternating finite element method (AFEM)

Subsurface defects by AFEM

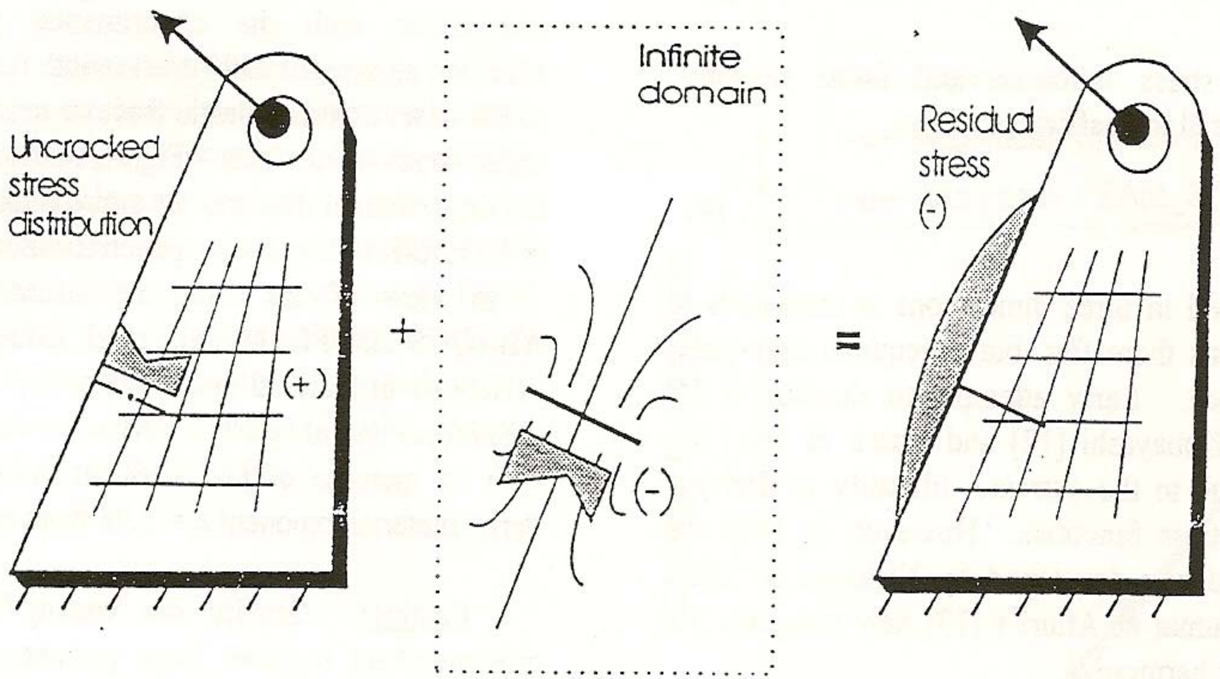


Uncracked FEM stress distribution (tensile)

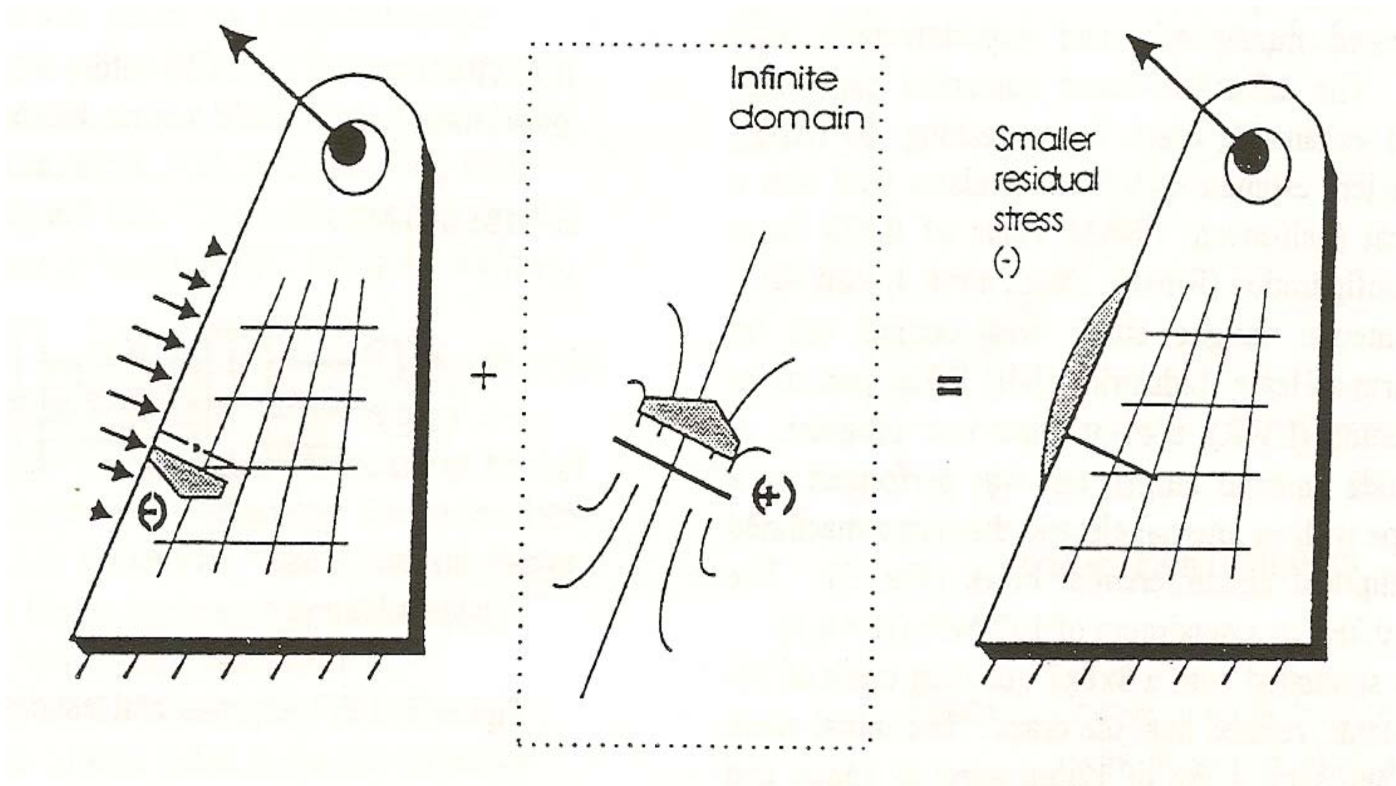
Crack stress field (compressive) in infinite domain

Stress-free surface (ie. crack) in component

Surface defects



Iterative corrections



Modified Forman crack growth

$$\frac{da}{dN} = \frac{C.(\Delta K)^n.(1-R)^m.[\Delta K - \Delta Kth]^p}{[(1-R).K_{Ic} - \Delta K]^q}$$

Lower bound: ΔKth (threshold K-factor)

Upper bound: KIc (fracture toughness)

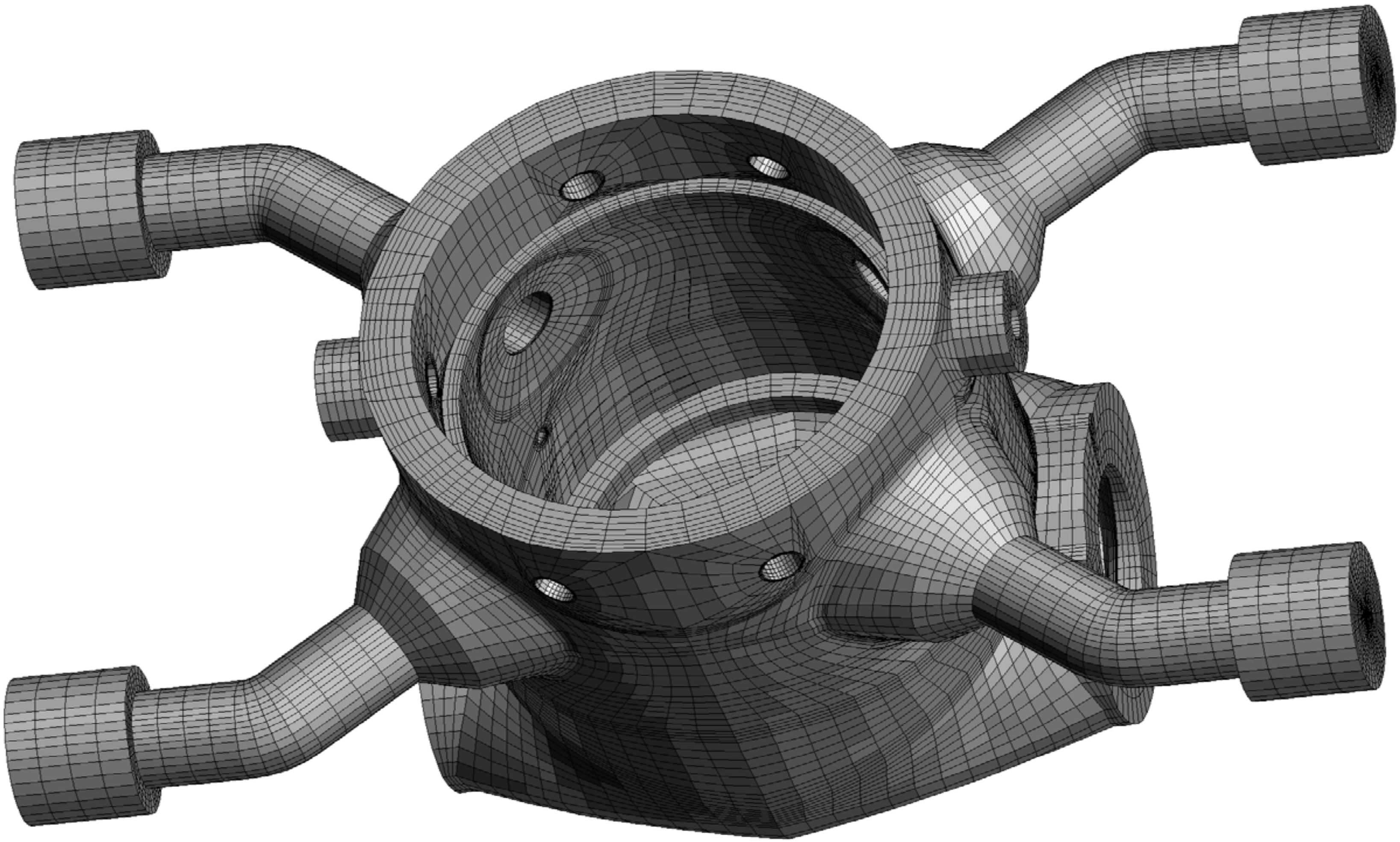
Different crack growth rates in base & carburized metal

Effect of Residual Stress Treatment

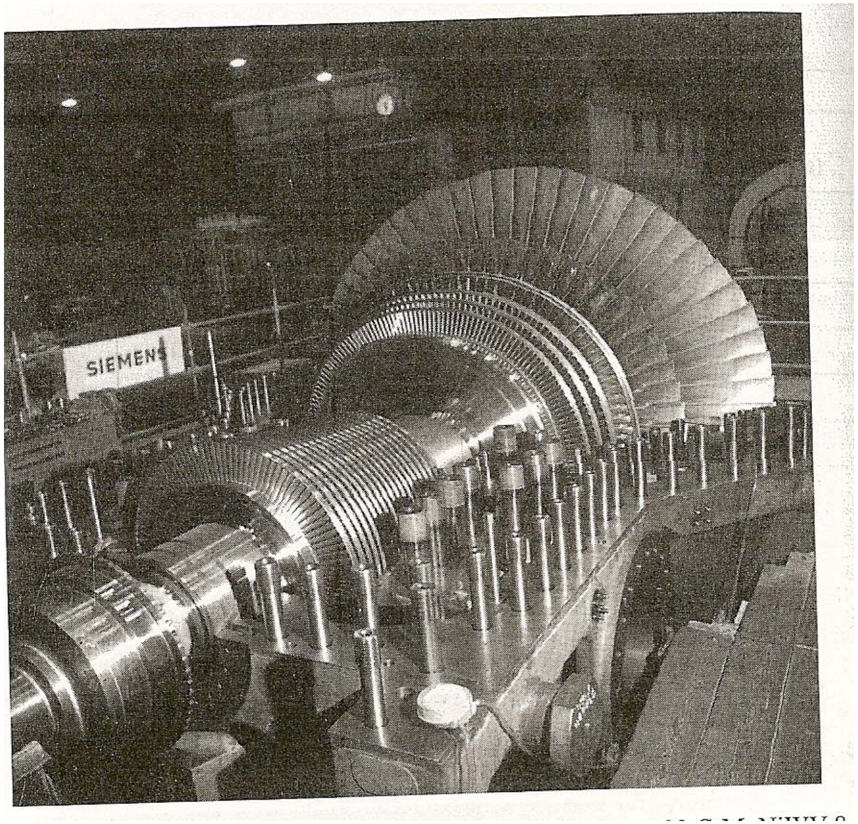
- Stress ratio = R
- = Min/Max stress
- = (Cyclic min + residual stress)
- --
- (Cyclic max + residual stress)

- where the exact process RS is used.

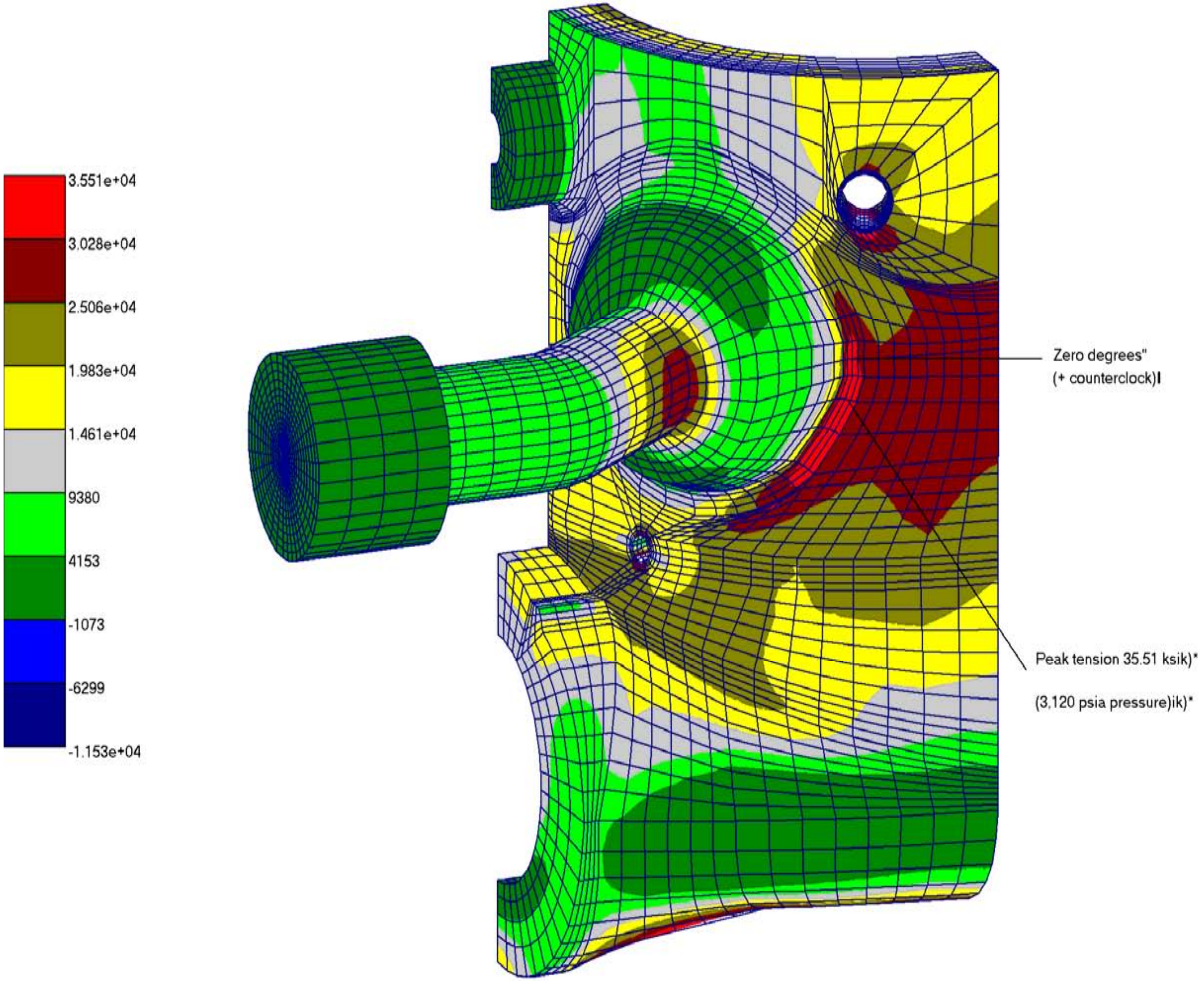
High-pressure turbine casing



HP, IP & LP turbine blades



Principal tensile stress



Typical surface cracking

Stress gradient

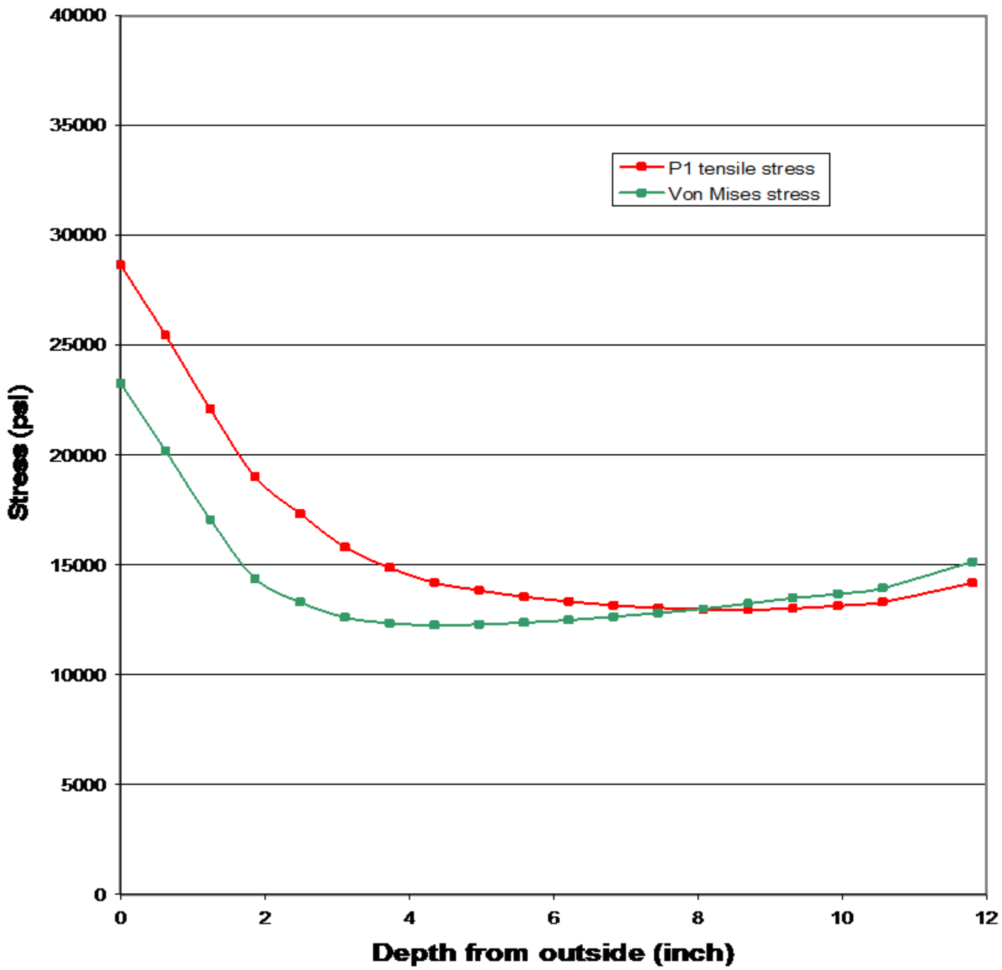
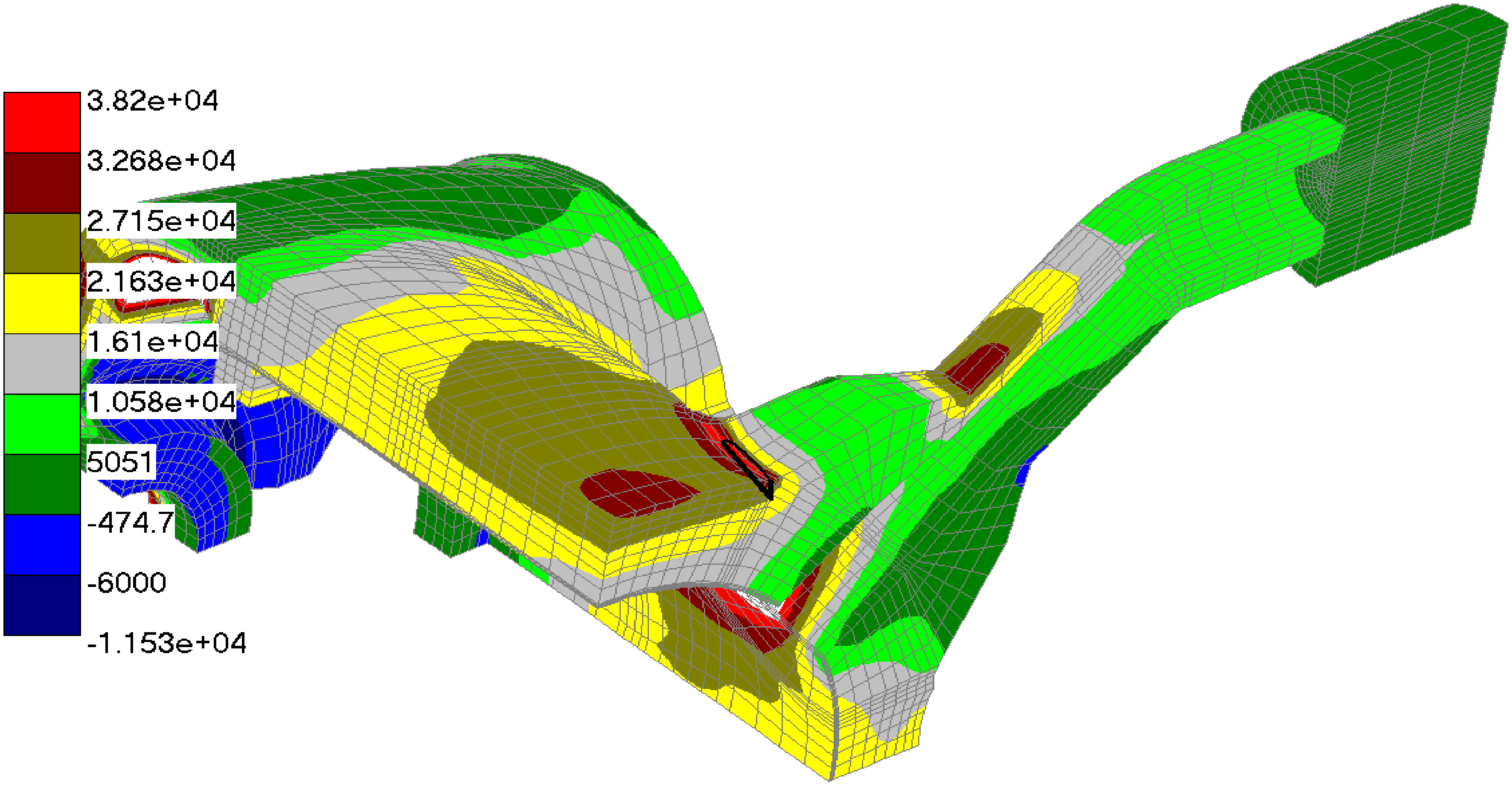
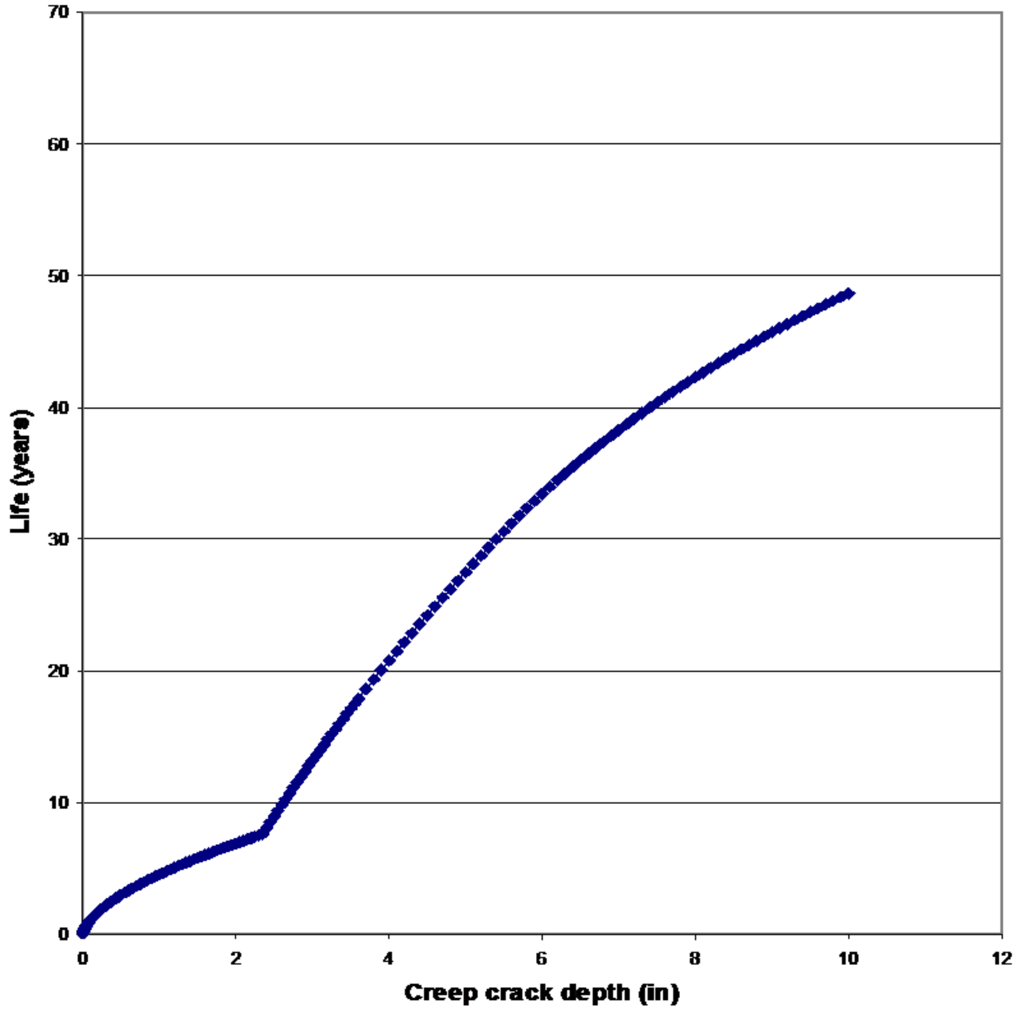


Fig. 10 Casing stress driving crack growth at 2520 psia

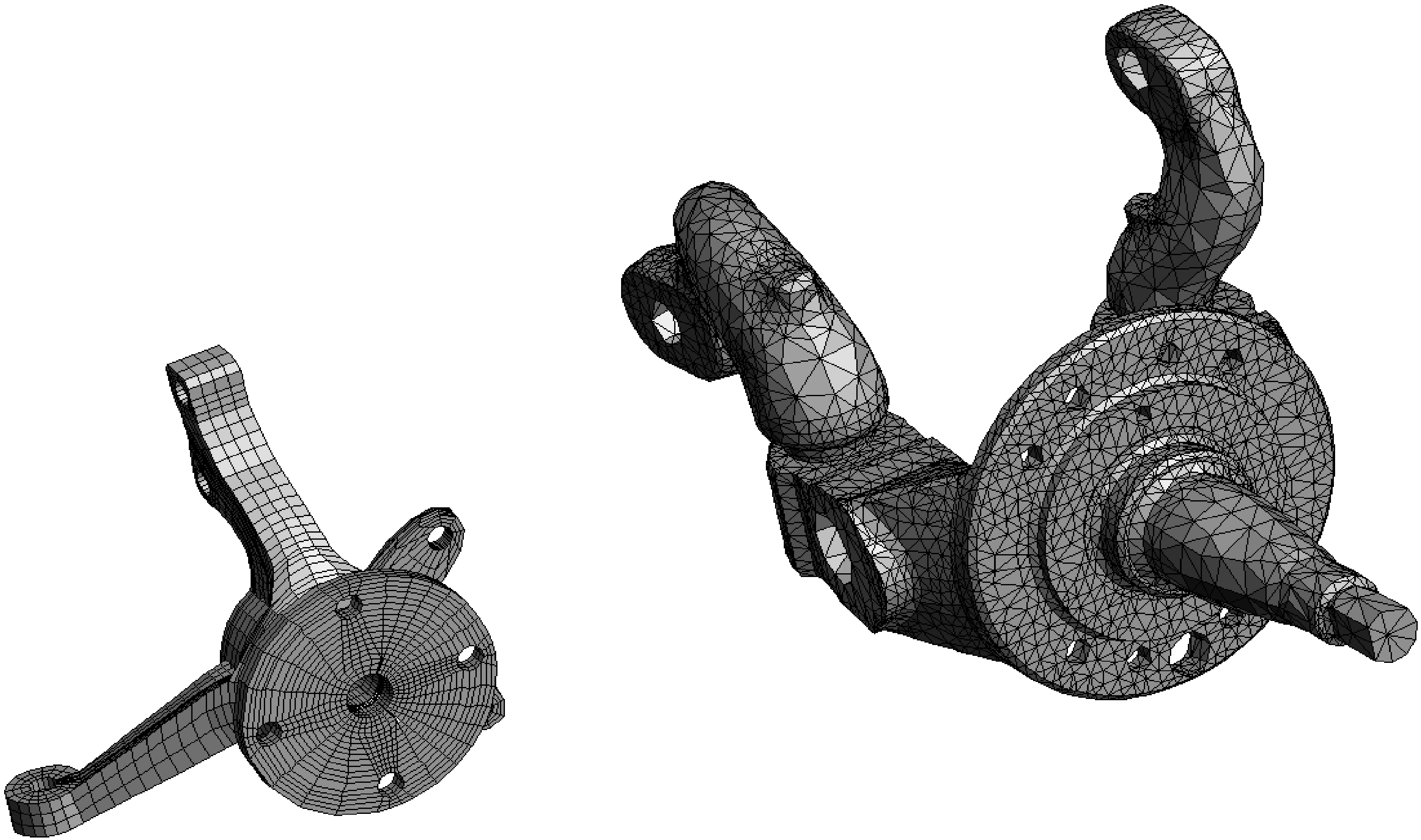
Superimposed surface crack



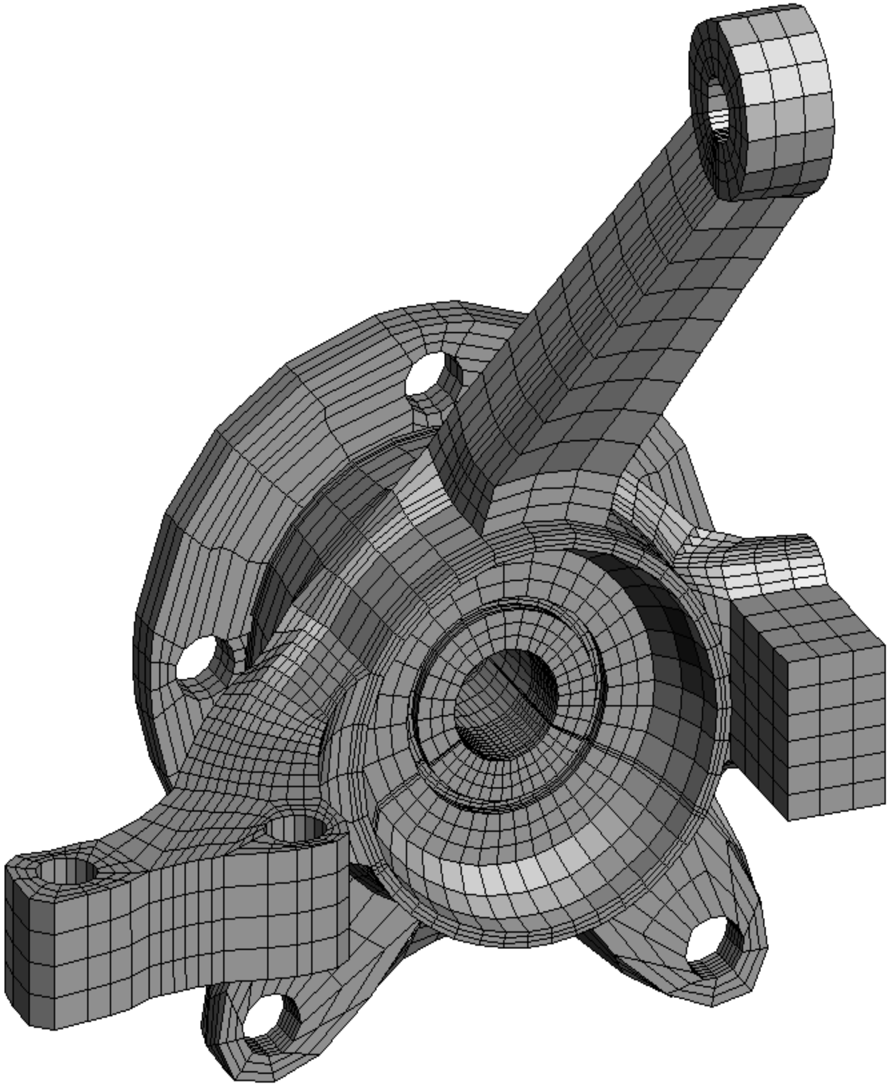
Crack depth vs lifecycles



Steering knuckles



Midsize sedan knuckle



Measured wheel loads time history

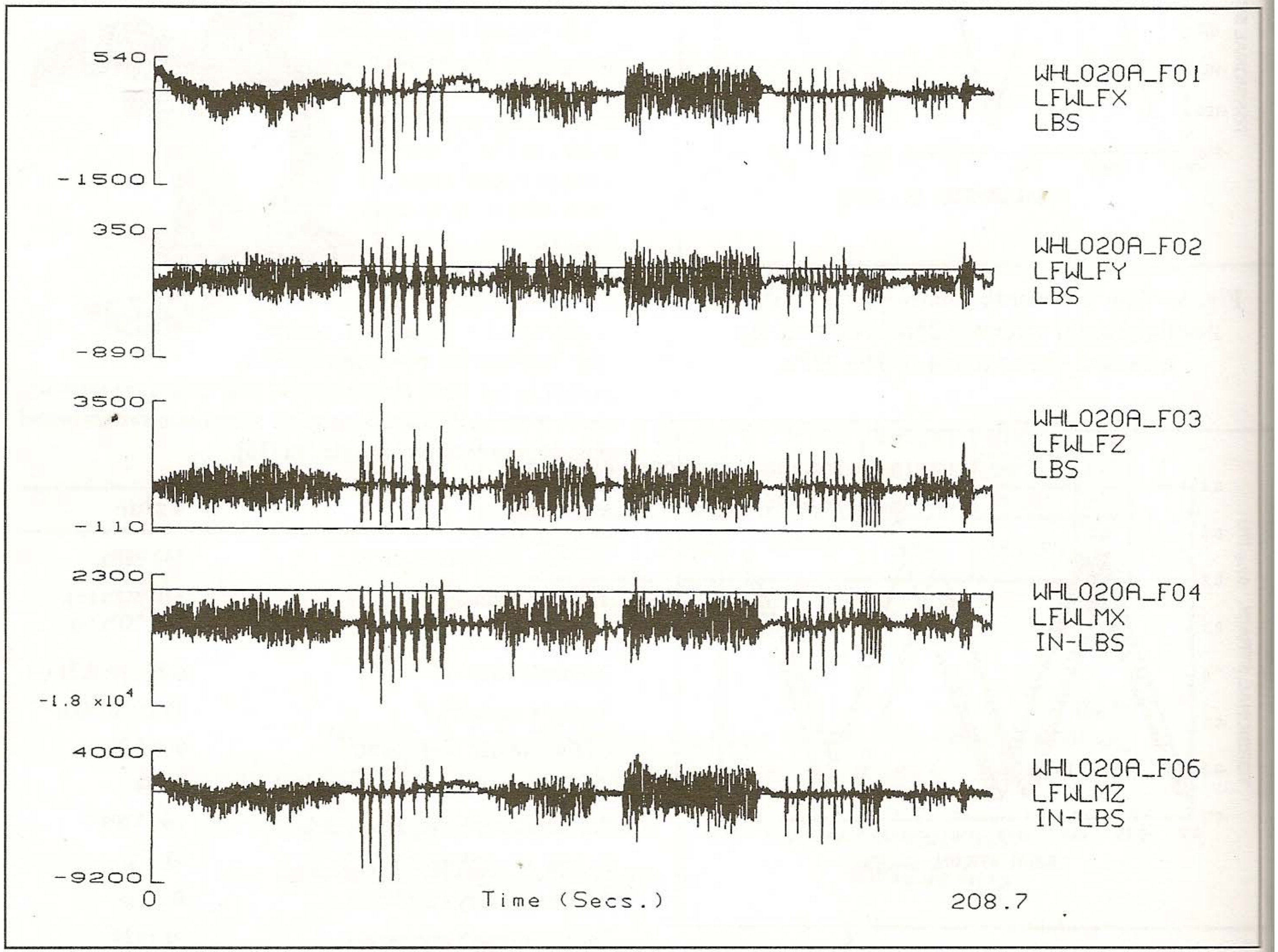
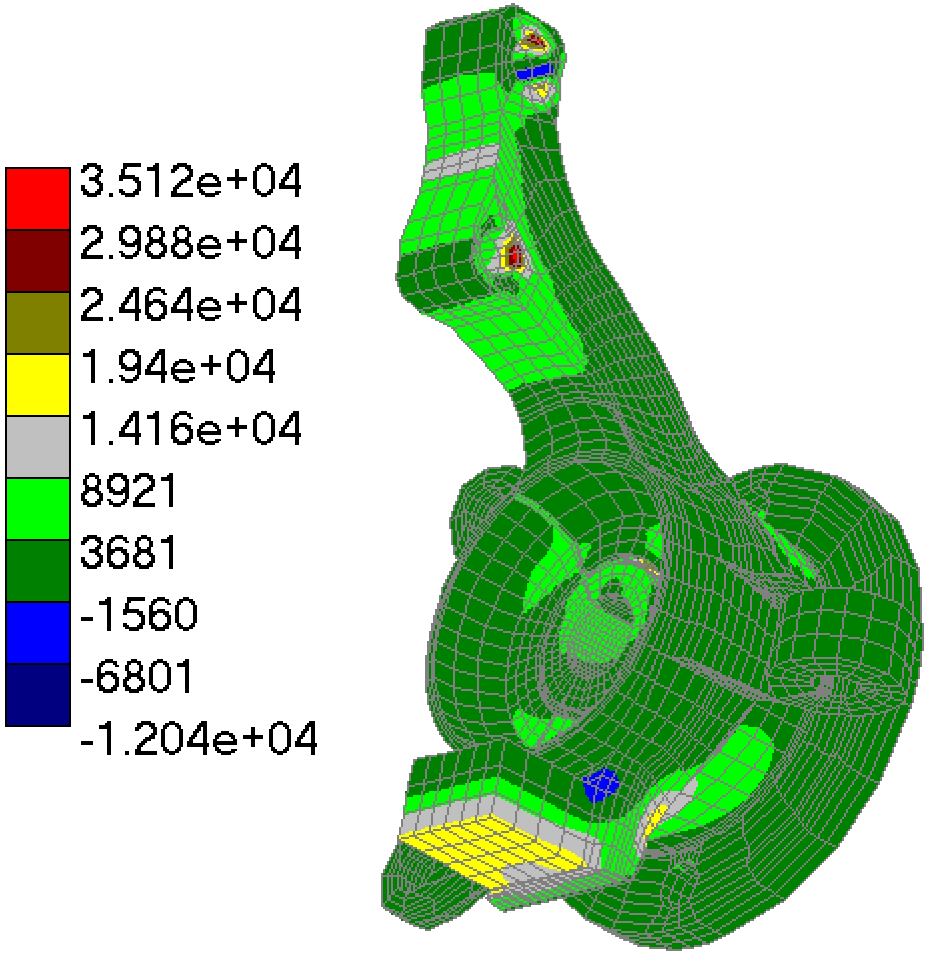
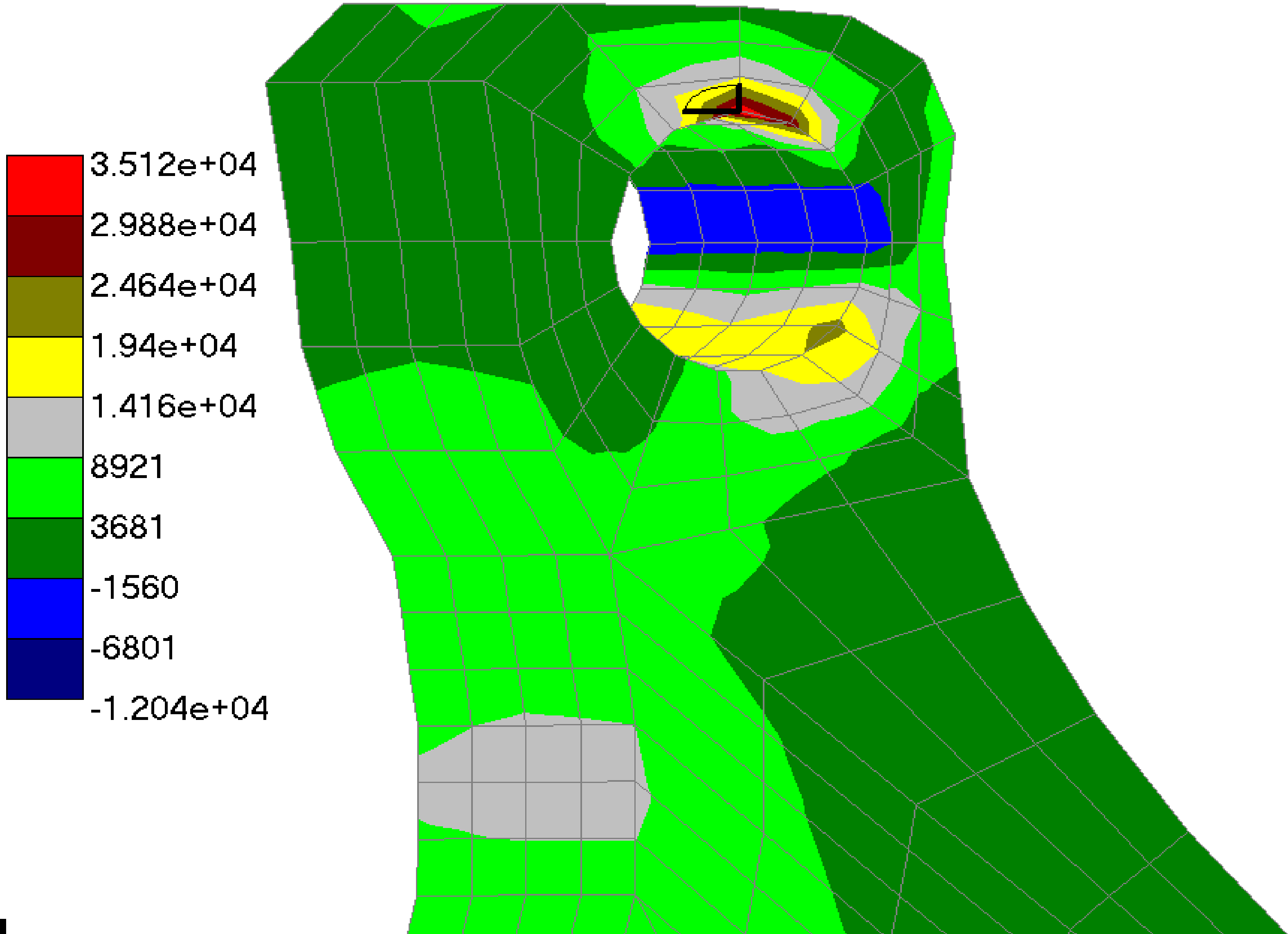


Fig. 11 - Measured wheel loads time history

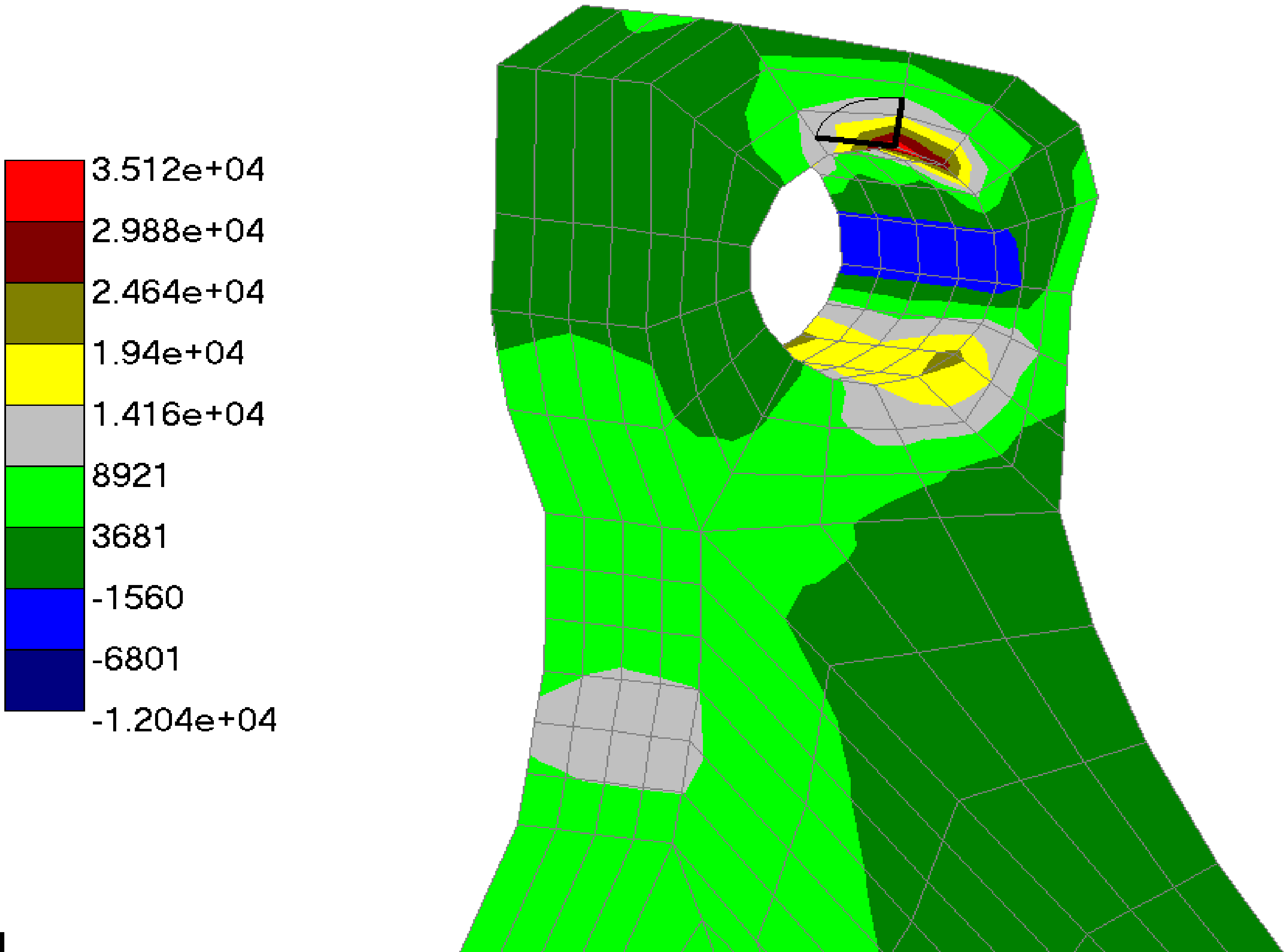
Principal tensile stress

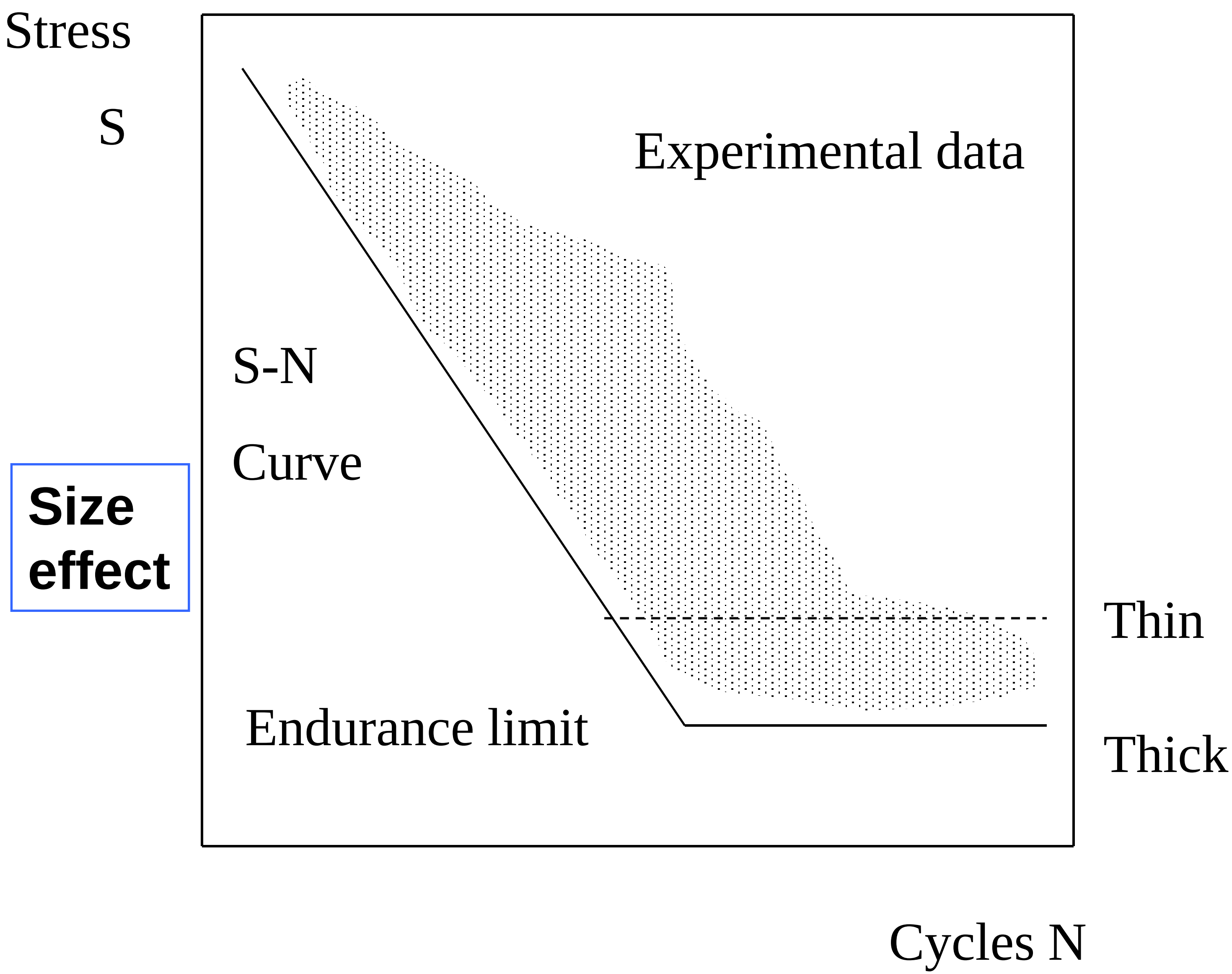


Corner crack at bolt hole



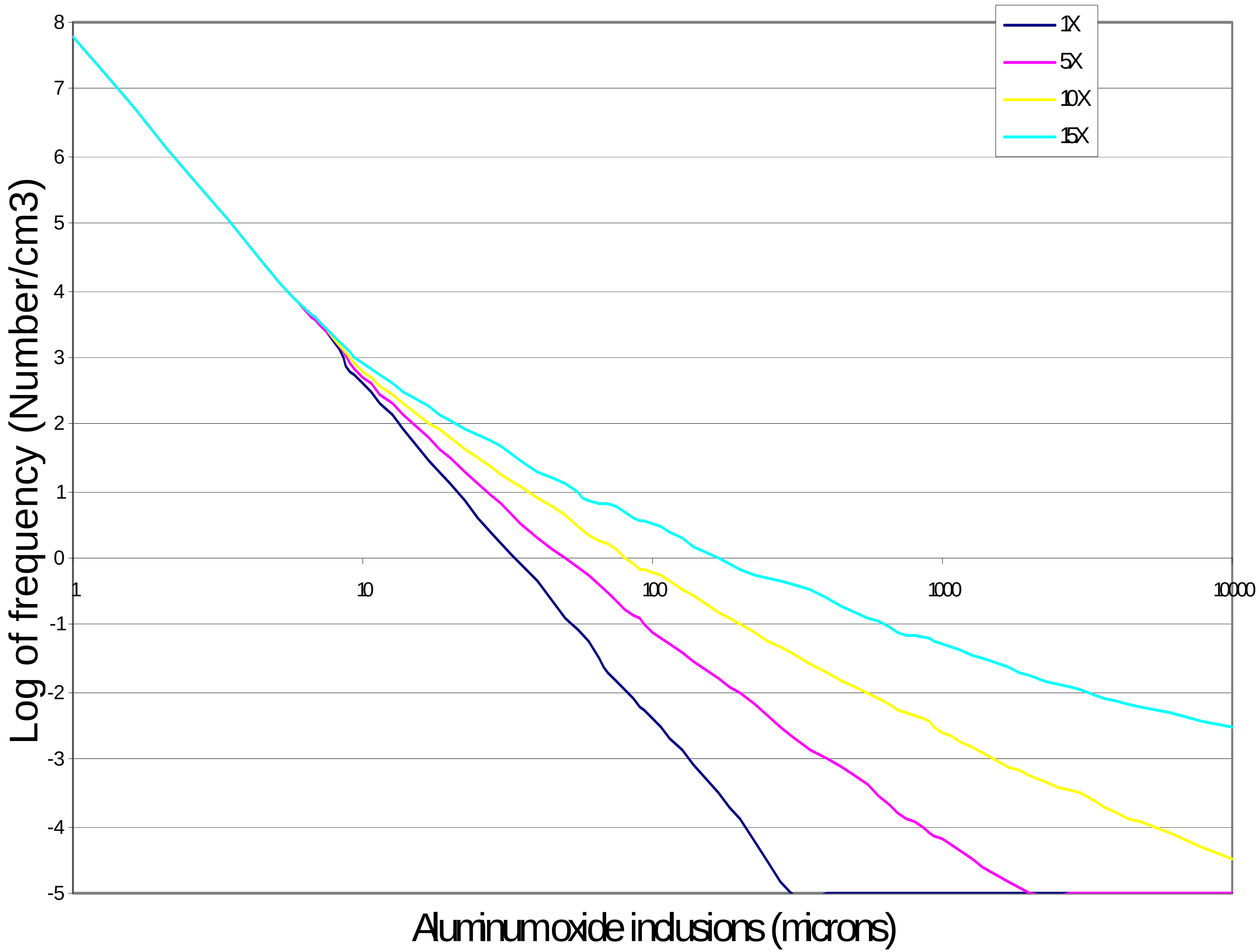
Corner crack growth




Stress
S
Experimental data
S-N
Curve
Size effect
Thin
Endurance limit
Thick
Cycles N

Fatigue specimen size effect?

- Stress life & strain life theories can not explain it
  - Explanation by stochastic fracture mechanics
  - Steelmakers data on inclusion & defect sizes
  - Large specimens -> more material -> more defects -> more variability -> shorter life


Log of frequency (Number/cm3)
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
1
10
100
1000
10000
Aluminumoxide inclusions (microns)
1X
5X
10X
15X

Summary

- Stochastic fracture mechanics →9.115% size effect
- Experimental tests → 10% size effect
- 1000s of Monte Carlo crack growth simulations performed by fast accurate Alternating Finite Element Method (AFEM)