ABAQUS/FE-SAFE™ FATIGUE CORRELATION

HEAT EXCHANGER APPLICATION

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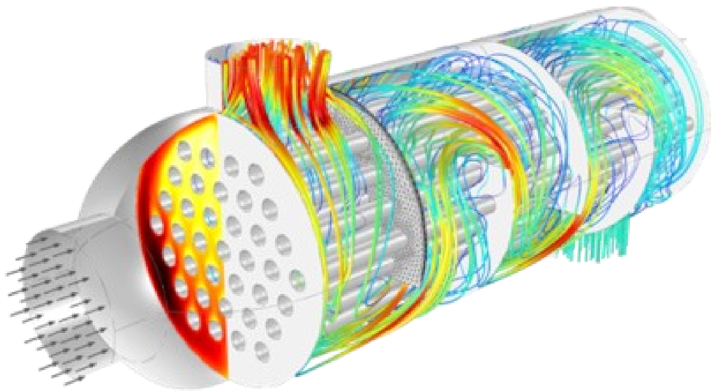
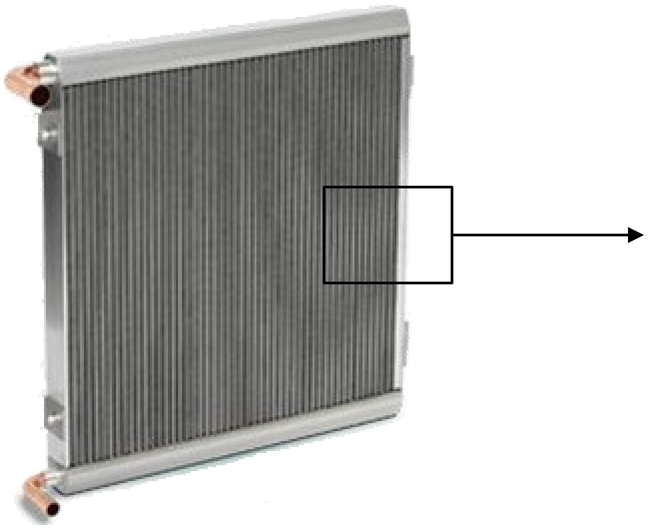
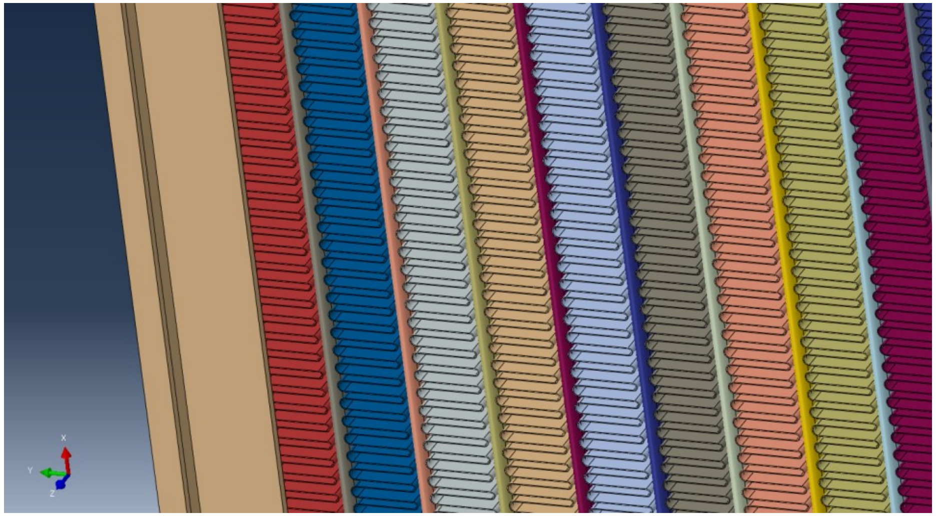


Heat Exchangers (HX)





Vertical tube HX with transverse cooling fins

Heat Exchanger (HX) Application

Small fin cracking in stress riser noticed in early testing

Believed to be aesthetic only

Actual *design* failures (i.e., fluid leaks) were *not* found

Customer investigated further for durability certainty

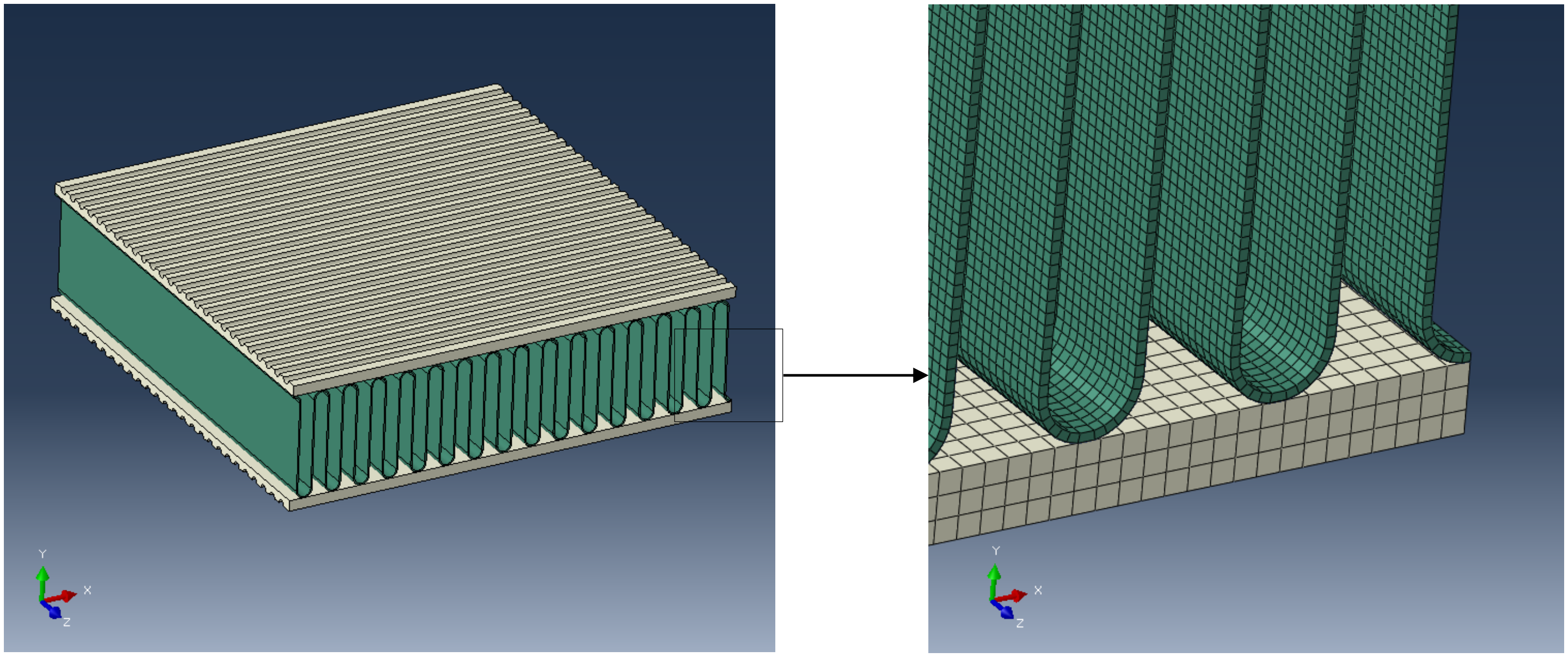
Heat Exchanger (HX) Application

Full-Scale HX modeled with Abaqus with pressure and thermal loads

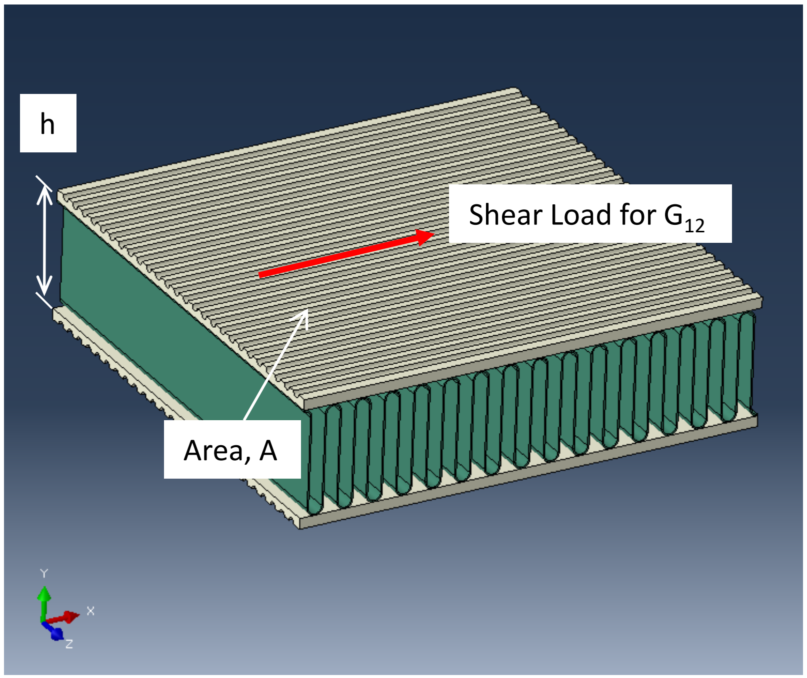
Sub-modeling technique to focus on stress riser

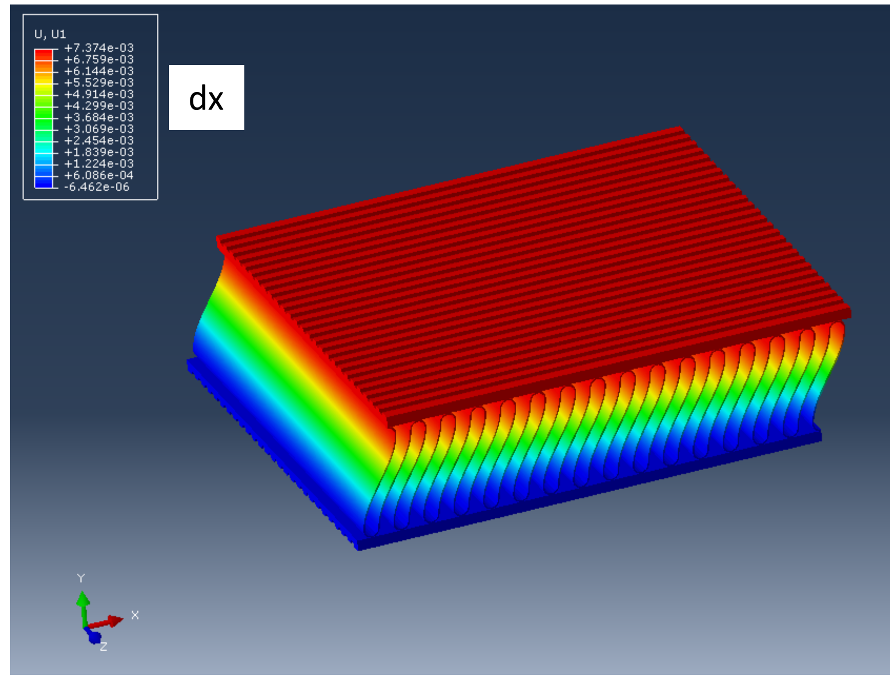
Fatigue analysis with fe-safe™

Correlation between analysis and test to calibrate



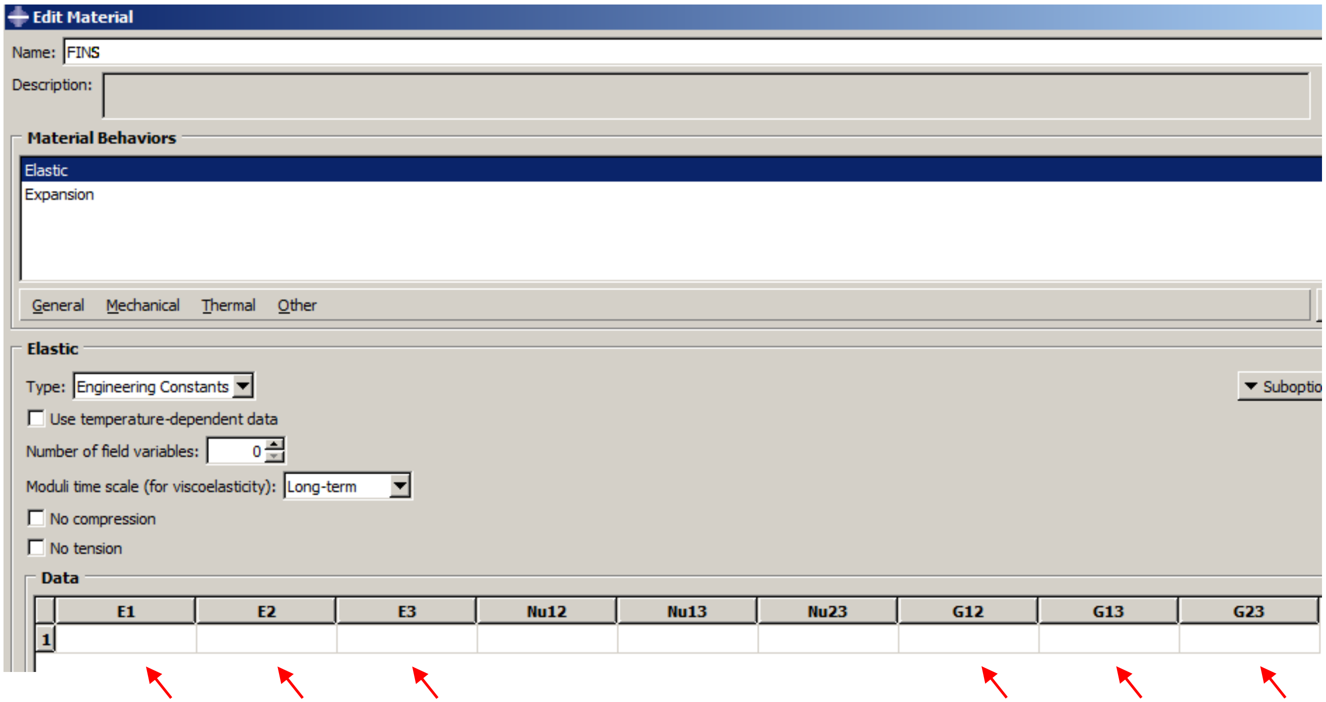
Model virtual coupons to develop stiffness response of the fins as sandwiched between tubes





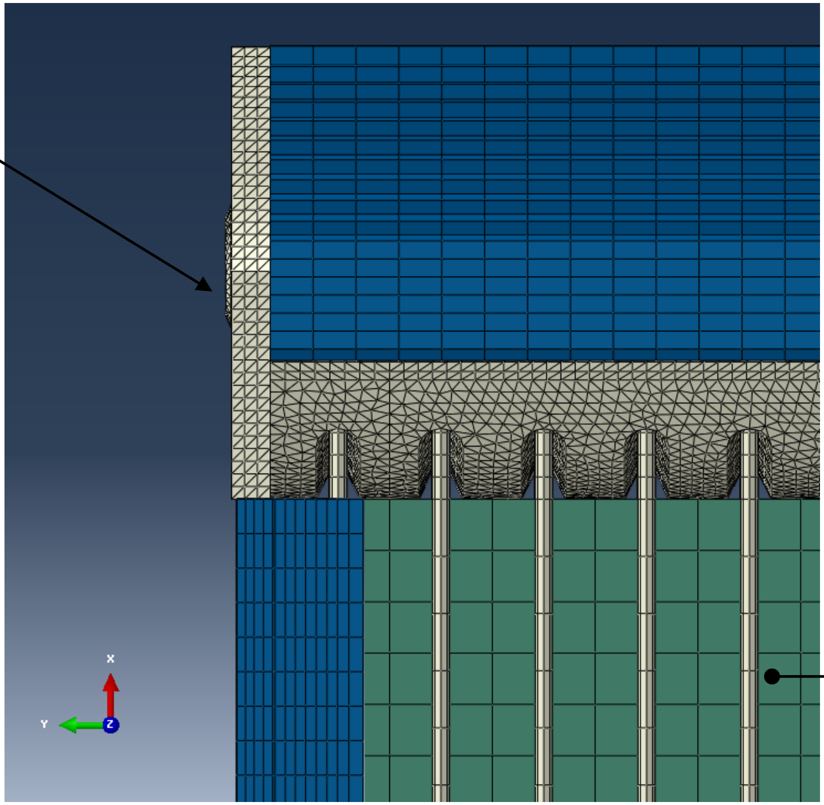
$$G_{12} = \frac{(Shear\ \ Load)\ h}{Adx}$$

Model virtual coupons to develop stiffness response of the fins as sandwiched between tubes



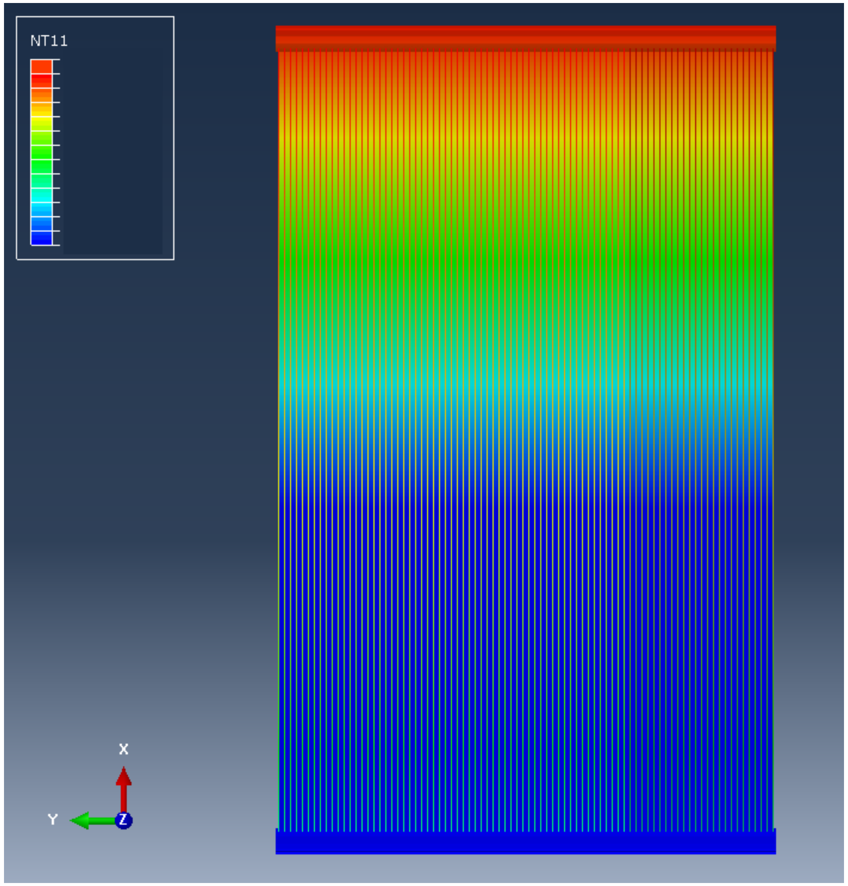
With Engineering Constants defining fin stiffness within brick elements, now proceed with a more manageable model

Discrete elements for all parts except fins



Non-isotropic properties for the fin acreage sections

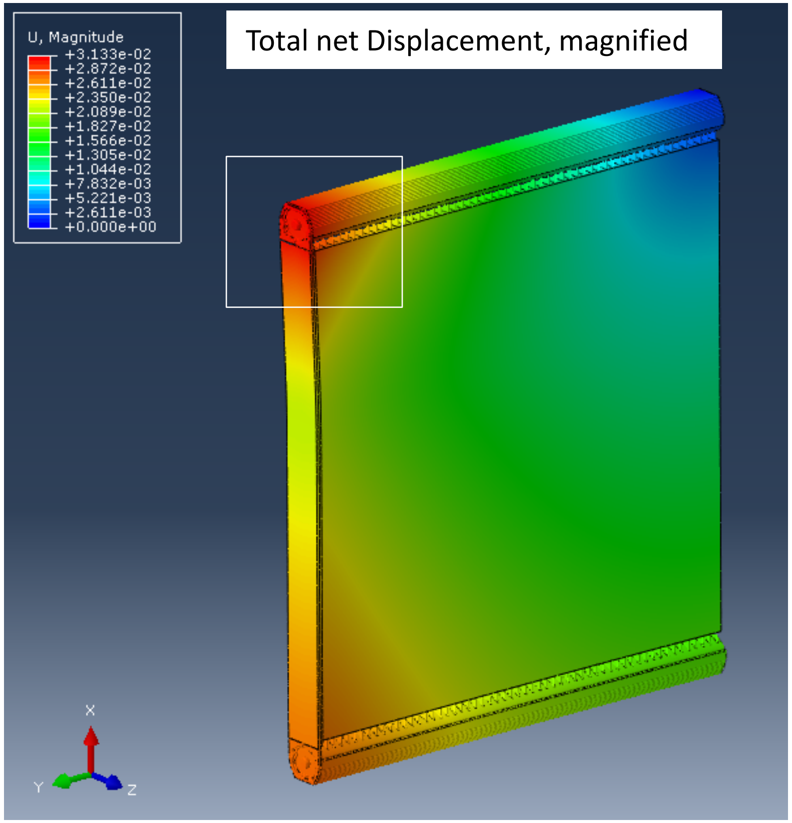
With Engineering Constants defining fin stiffness within brick elements, now proceed with a more manageable model



Thermal map from test lab process and data provided from customer

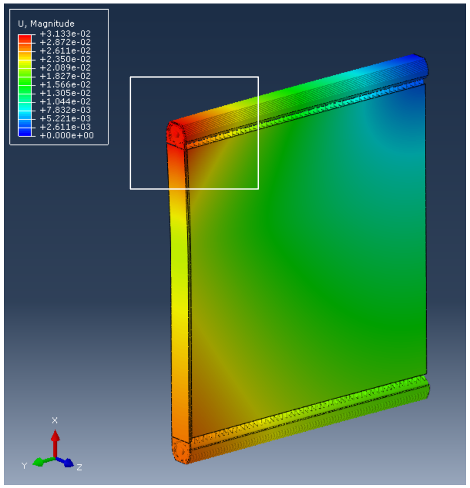
Internal tube pressure also applied

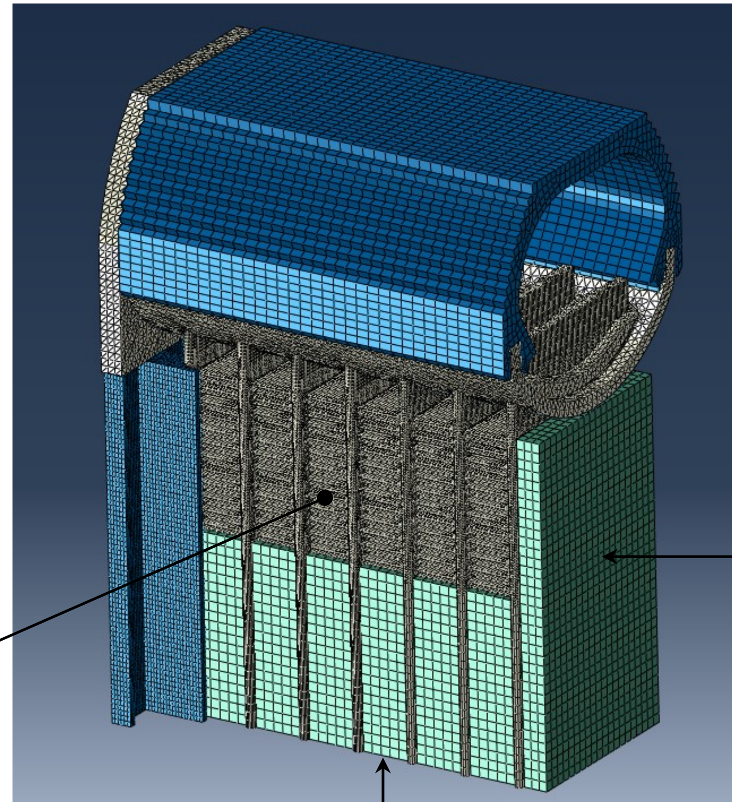
Run the large global model inclusive of the entire assembly



Main purpose of the global model is to find a displacement map throughout the X, Y, Z space

The global model also finds more highly stressed zone(s)

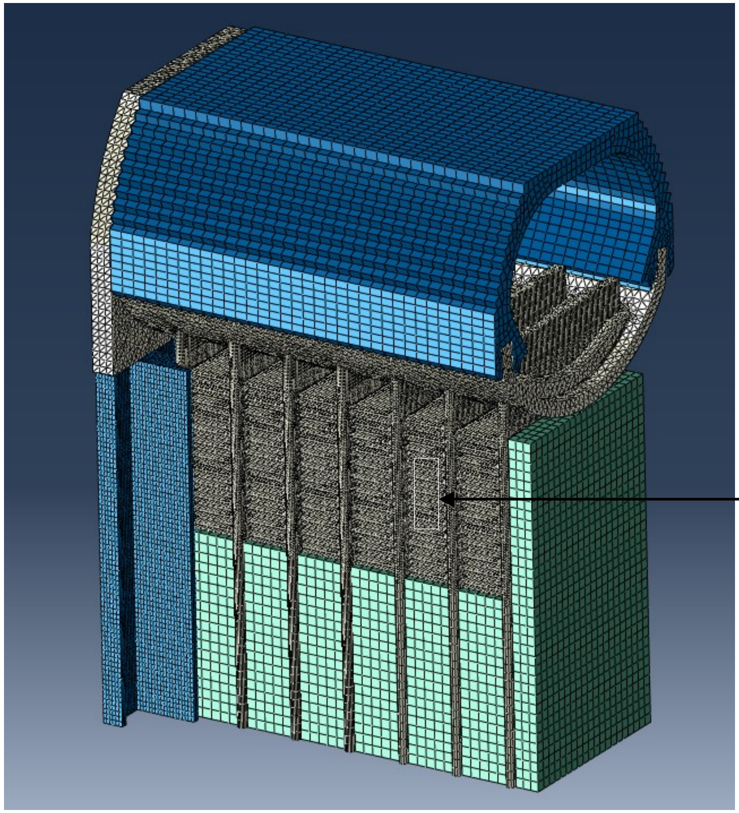




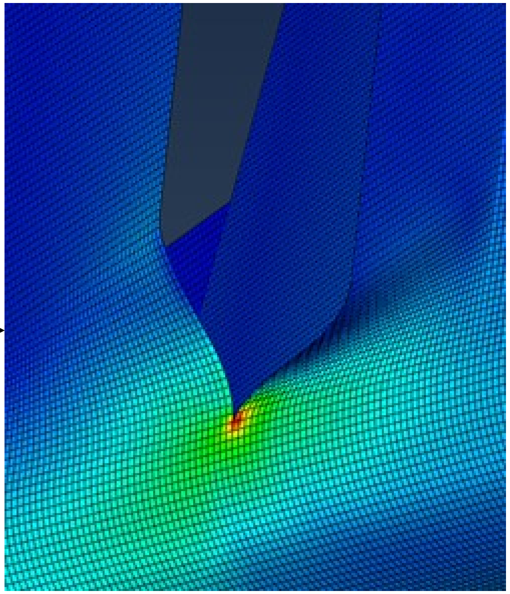
Fins are now discretely meshed

Sub-model boundary plane

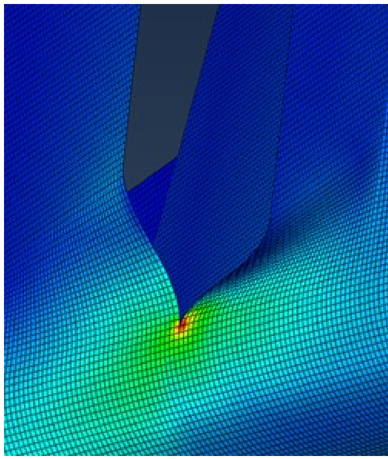
Sub-model boundary plane



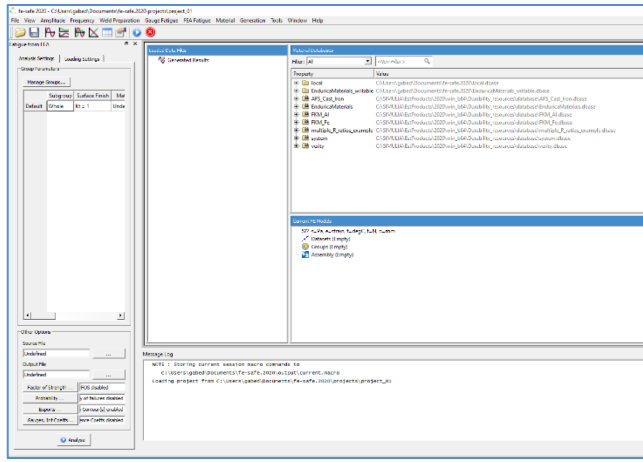
Multi-axial stress seen
in sharp corner



Although the fins appear to be 2D in shape, there are also 3D features along the length – one of which creates a stress riser



Abaqus output

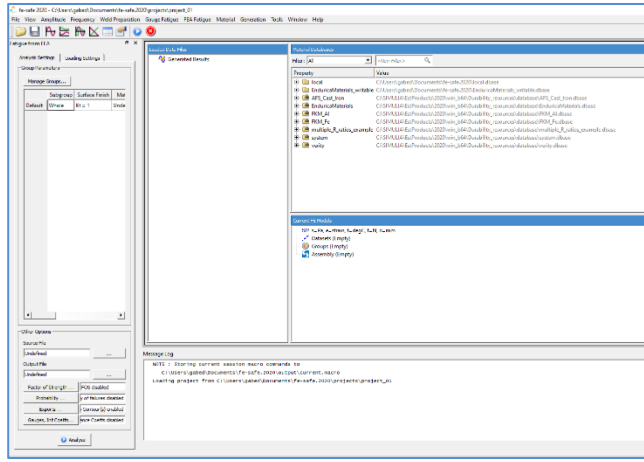


fe-safe ™

N Cycles

Cycle count results

$$n_{fes} = 1.000$$



N Cycles

Results from fe-safe™ :

Actual results proprietary

Normalize with: $\mathbf{N_{fes} = n_{fes} \times K/b}$

n_{fes} (normalized result) = 1.000

$$n_{fes} = 1.000$$

$$N_{fes} = 1.000\,\frac{K}{b}$$

Some fe-safe^{TM} notes:

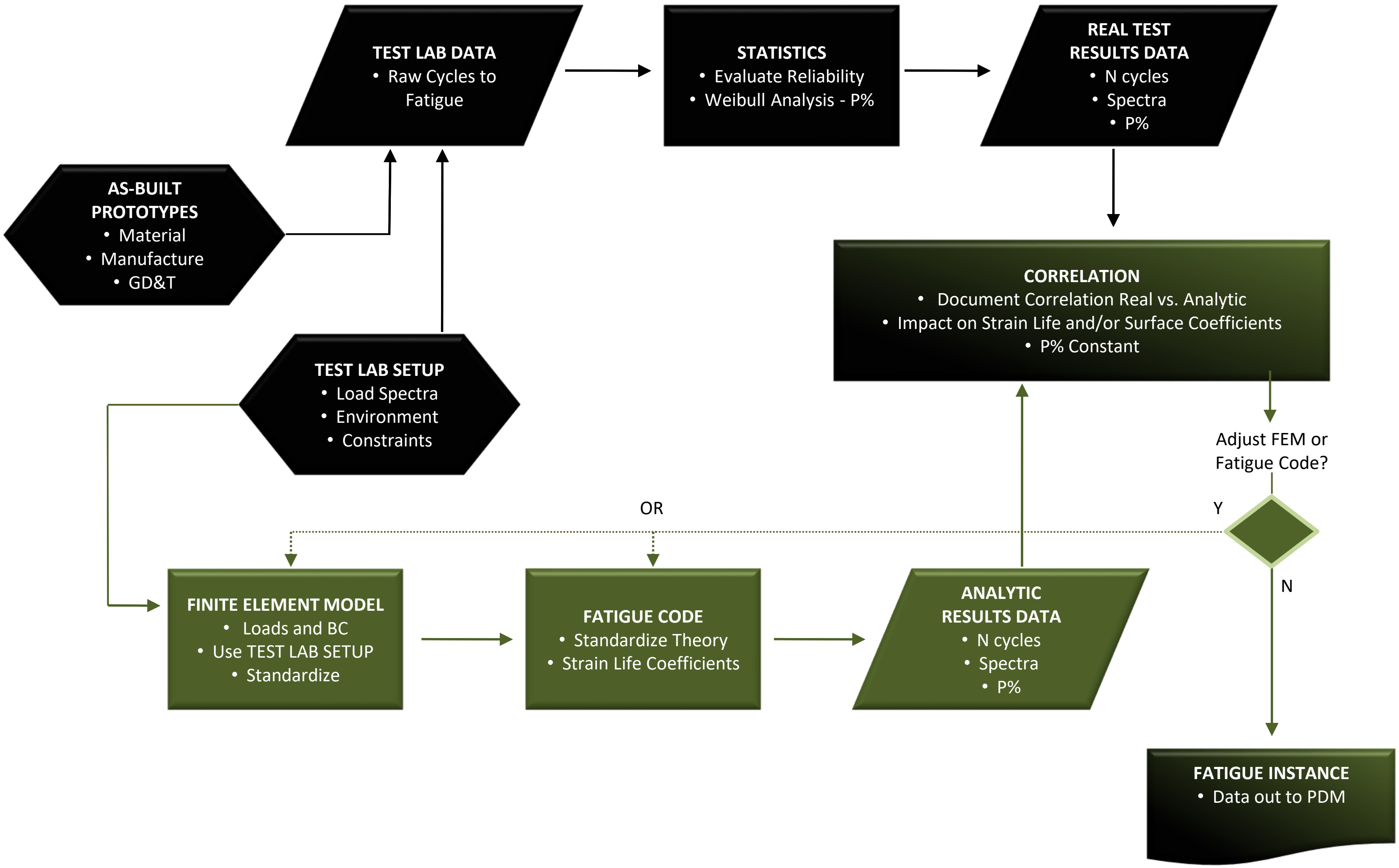
Mostly defaults

Linear material with the built-in Nueber's rule

For strain life properties, used the built-in Seegar's rule and textbook strength values at the maximum temperature

Due to extreme stress-riser, import stresses from elemental centroid

Completed ***February 2021***


TEST LAB DATA
• Raw Cycles to Fatigue
STATISTICS
• Evaluate Reliability
• Weibull Analysis - P%
REAL TEST RESULTS DATA
• N cycles
• Spectra
• P%
AS-BUILT PROTOTYPES
• Material
• Manufacture
• GD&T
CORRELATION
• Document Correlation Real vs. Analytic
• Impact on Strain Life and/or Surface Coefficients
• P% Constant
TEST LAB SETUP
• Load Spectra
• Environment
• Constraints
Adjust FEM or Fatigue Code?
OR
Y
N
FINITE ELEMENT MODEL
• Loads and BC
• Use TEST LAB SETUP
• Standardize
FATIGUE CODE
• Standardize Theory
• Strain Life Coefficients
ANALYTIC RESULTS DATA
• N cycles
• Spectra
• P%
FATIGUE INSTANCE
• Data out to PDM

Physical lab testing results, using the same temperature and pressure profile as analysis

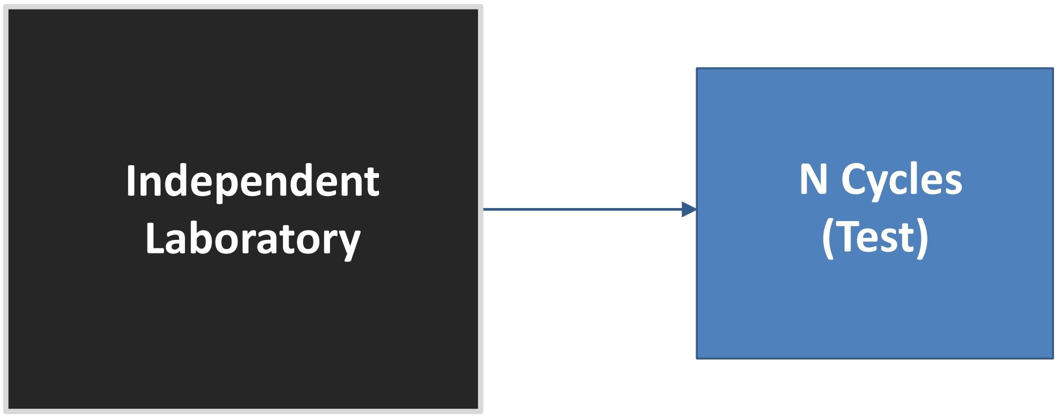
3rd party independent lab results are proprietary

Use the same function: **$N_{lab} = n_{lab} \times K/b$**

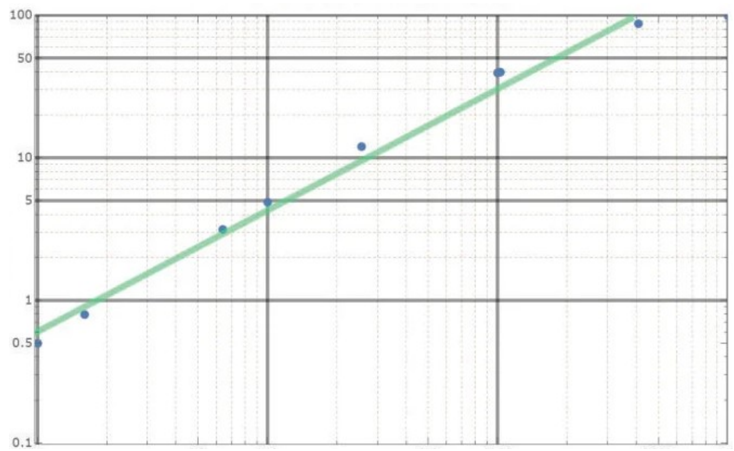
Completed ***November 2021***

$$N_{lab} = n_{lab}\,\frac{K}{b}$$

$$n_{lab} = ?$$



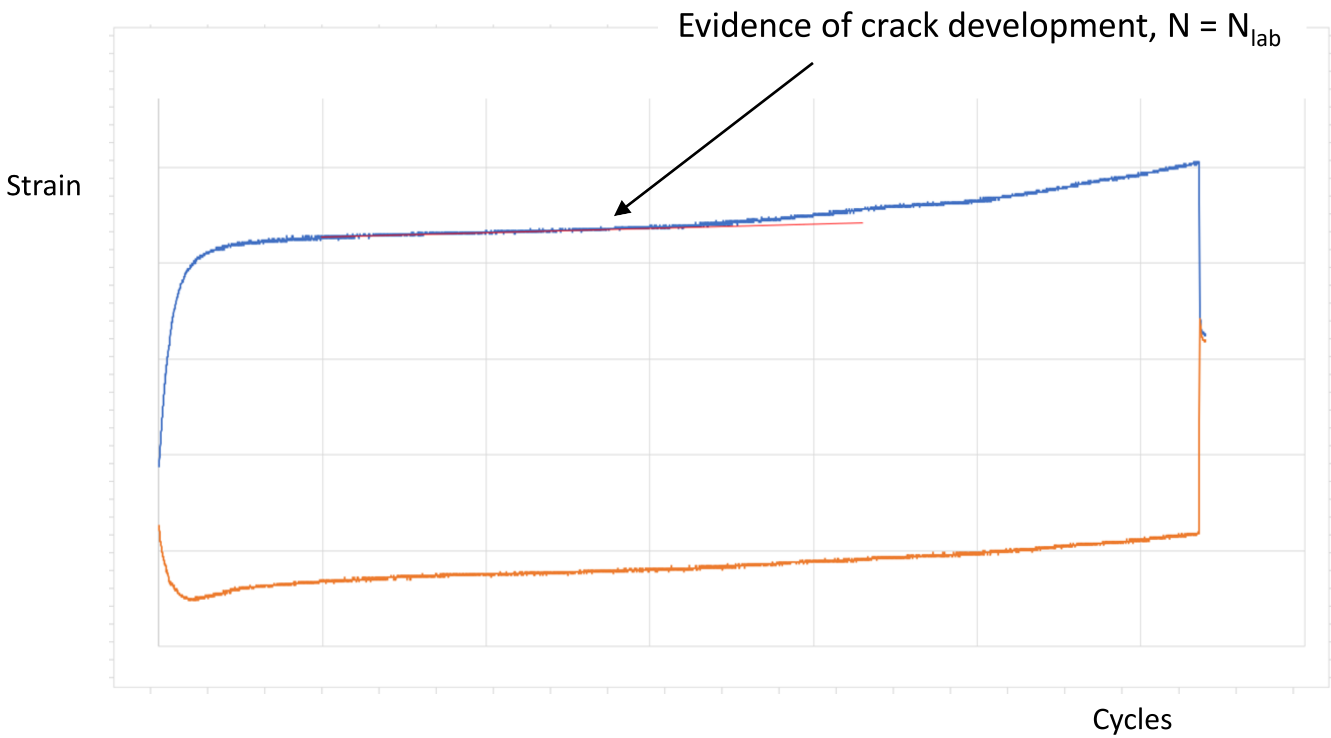
Physical lab testing results, data development



Visual observation of cracking produced wide scatter

Strain gages placed near area around crack observation

Physical lab testing results, data development



From strain gages, track change in strain/displacement

Physical lab testing results

Now with a better-defined N result from the lab

Find n for lab result using the same function: $\mathbf{N_{lab} = n_{lab} \times K/b}$ for comparison to fe-safe™ result

$$N_{lab} = \text{from testing}$$

$$N_{lab} = n_{lab} \frac{K}{b}$$

$$n_{lab} = ?$$

Physical lab testing results

Now with a better-defined N result from the lab

Find n for lab result using the same function: $\mathbf{N_{lab} = n_{lab} \times K/b}$ for comparison to fe-safe[TM] result

$$N_{lab} = \text{from testing}$$

$$N_{lab} = n_{lab} \frac{K}{b}$$

$$n_{lab} = 1.028$$

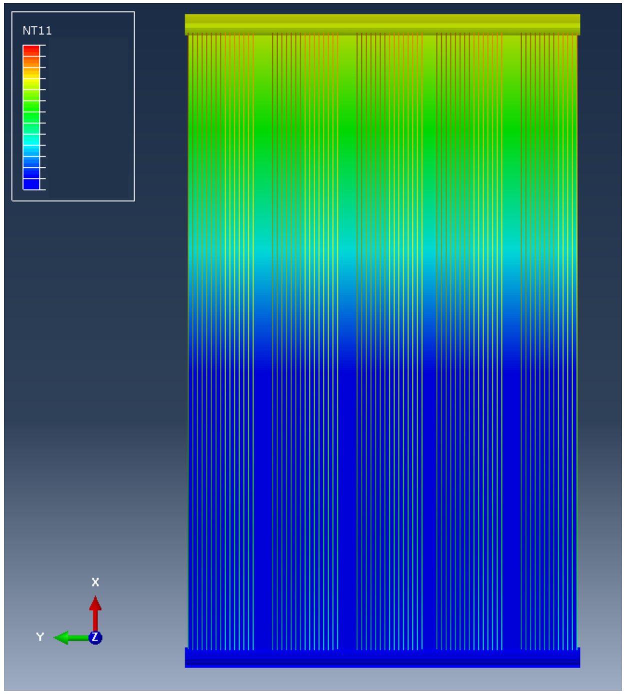
~3% delta

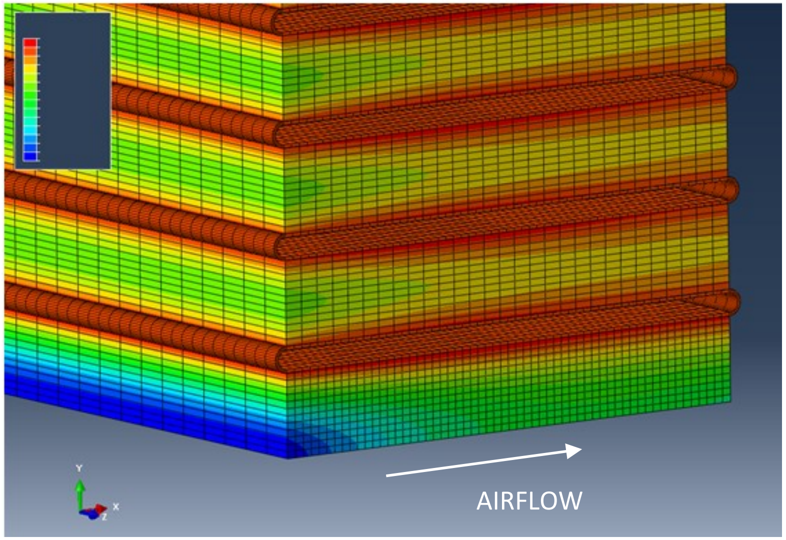
Calibration utilization

Given excellent calibration, we have high confidence in using the FE method, assumptions, and the fe-safe™ parameters to:

- Quantitatively compare lab results to expected field results
- Study new designs
- Optimize thicknesses or other design features

For example: running the same analysis process using field service loads led to high confidence in the expected durability versus requirements of the design in the field

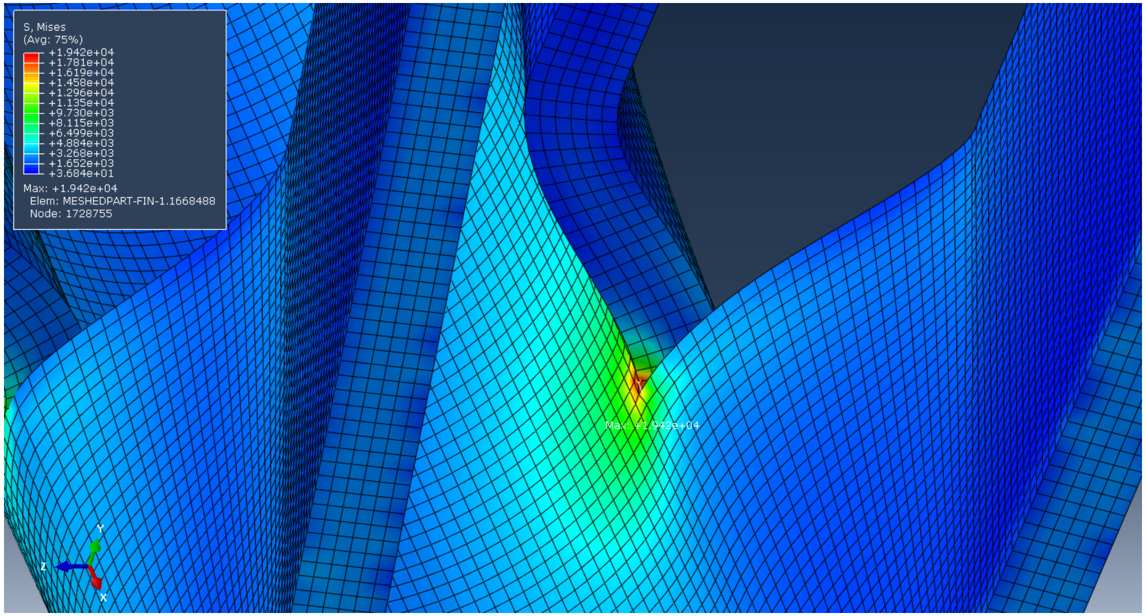




Field service thermal map provided from CFD including 3D effects

As an additional study of the fe-safe™ method, the fin sub-model, which was originally made with shell elements, was also made using brick elements

The fatigue analysis results were nearly identical as per the shell element model



Summary

Small fin cracking in stress riser noticed in early testing *proved* to be aesthetic only

Excellent correlation between test and analysis lead to high confidence in design durability vs. field requirements

High confidence also obtained in methodology and assumptions for further design optimizations