ICAF 2023 – the 38th Conference and 31st Symposium of the International Committee on Aeronautical Fatigue and Structural Integrity

STRUCTURAL INTEGRITY IN A WORLD IN TRANSITION

Tools and Methods for Landing Gear Fatigue Analysis with Surface Treatment Effects

31ST SYMPOSIUM OF ICAF, 26–29 JUNE 2023, DELFT, NETHERLANDS

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Contributing Organisations

1. **United States Air Force**
   - Supply Chain Management.
   - Landing Gear Systems.
   - *Requirements / End Customer / End User.*

2. **HOTTINGER BRÜEL & KJÆR**
   - Sensors and measurement systems.
   - *Software for durability and reliability.*
   - *Methods development and mechanical testing for fatigue performance characterisation.*

3. **Select Engineering Services**
   - Engineering and technical services and products to US DoD.
   - *Test programme management and fatigue analysis integration tools development.*

4. **General Atomics**
   - *Systems Integration.*

Introduction

- In 2022, in the USA the “Air Force Times” reported:

  “The USAF service’s aircraft now average 29 years old; … When planes get old, they inevitably need more maintenance — on a day-to-day basis or as part of more intensive overhauls that extend an aircraft’s life …”

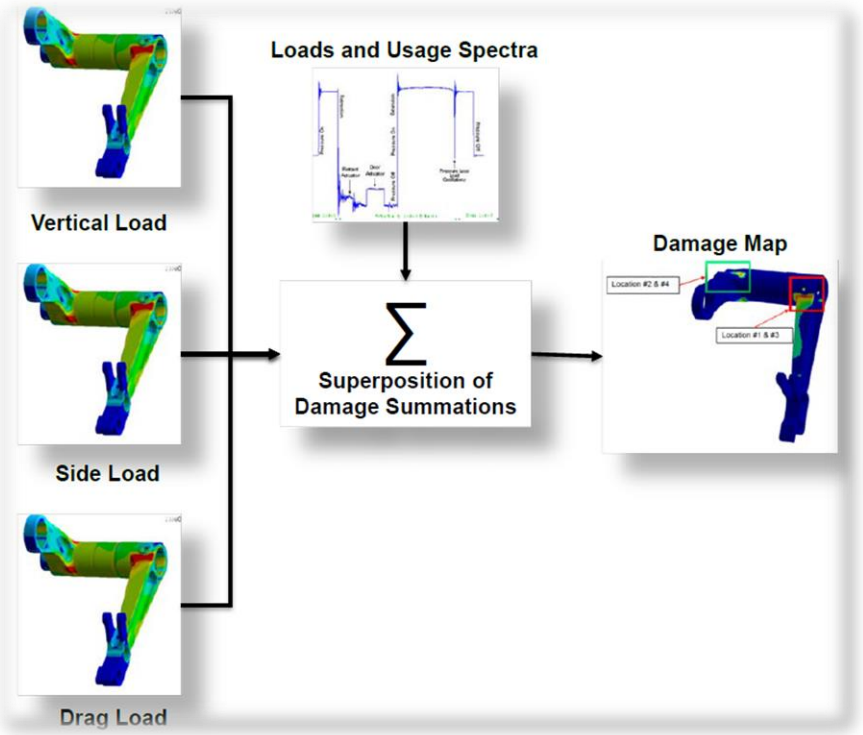
- Protective coatings and processes (surface treatments) are applied to landing gear components to control their dimensionality and to protect their structural integrity.

- These surface treatments affect surface material properties and multiple coatings can be applied, stripped and re-applied during overhaul.

- These surface treatments have known detrimental effects on fatigue life but were not considered in legacy USAF design.

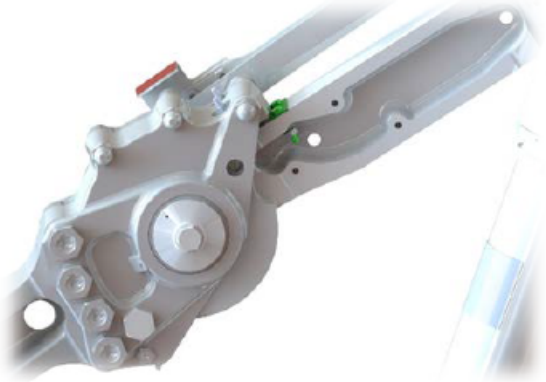
Agenda

1. **USAF Landing Gear Systems**
   - Basic LG Design Issues
   - What is Considered in Landing Gear Repair and Design?
   - Contemporary Landing Gear Analysis
   - Landing Gear Systems
   - Advances in Safe Life Analysis
2. HBK Advanced Materials Characterisation & Testing
3. Select Engineering Services



Basic LG Design Issues

- **Safe Life Design**
  - Design - 4 Lives / Test - 2 Lives / Fly - 1 Life
- **Common Failure Modes of LG Materials**
  - General Corrosion
  - Grinding Burns
  - Stress Corrosion Cracking (SCC)
  - Hydrogen Embrittlement (HE)

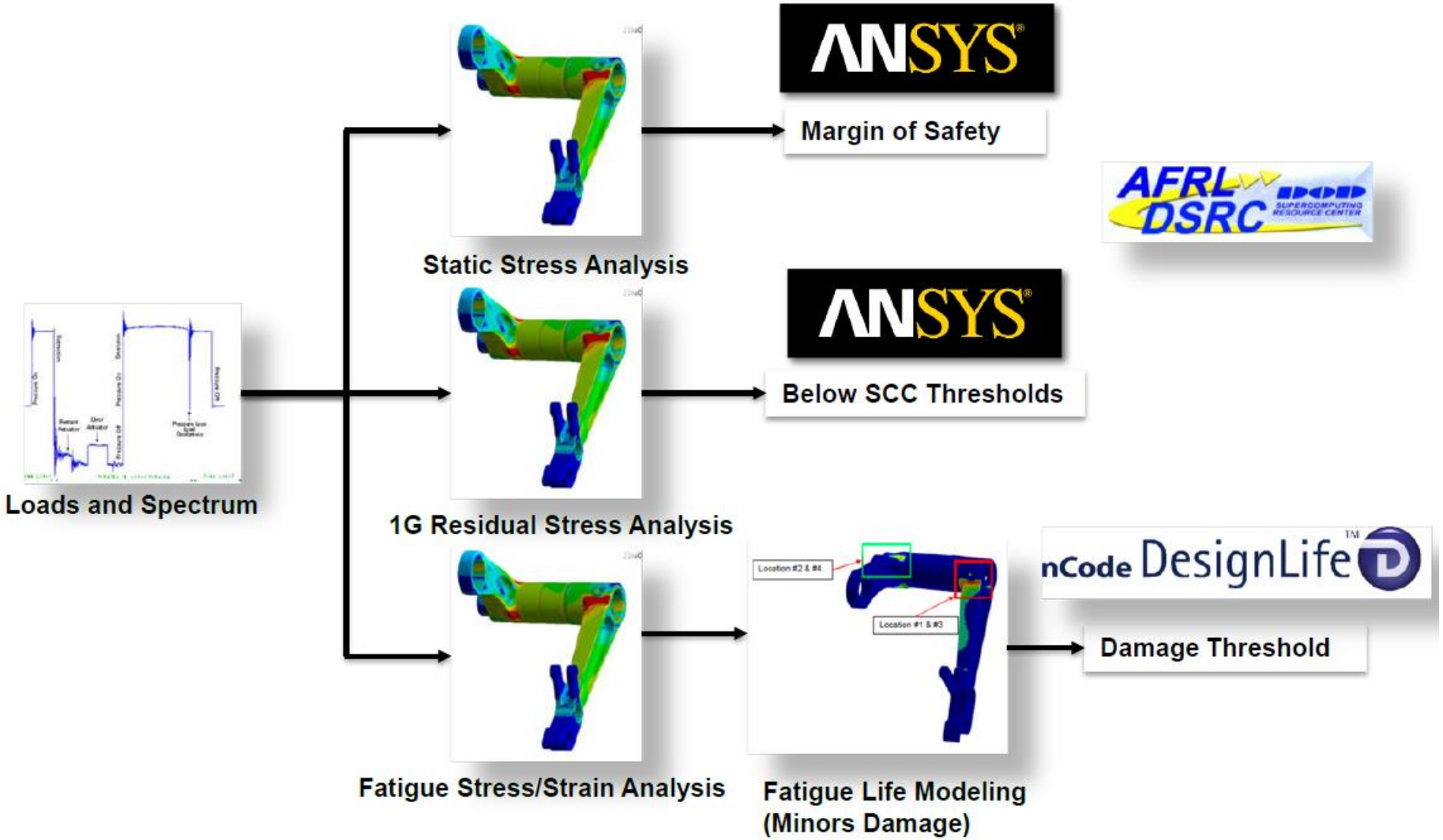


- **Protective Coatings & Processes**
  - Coatings – Protect Against Corrosion
  - Process – Controlled: Reduce Risk HE & Grinding Burns

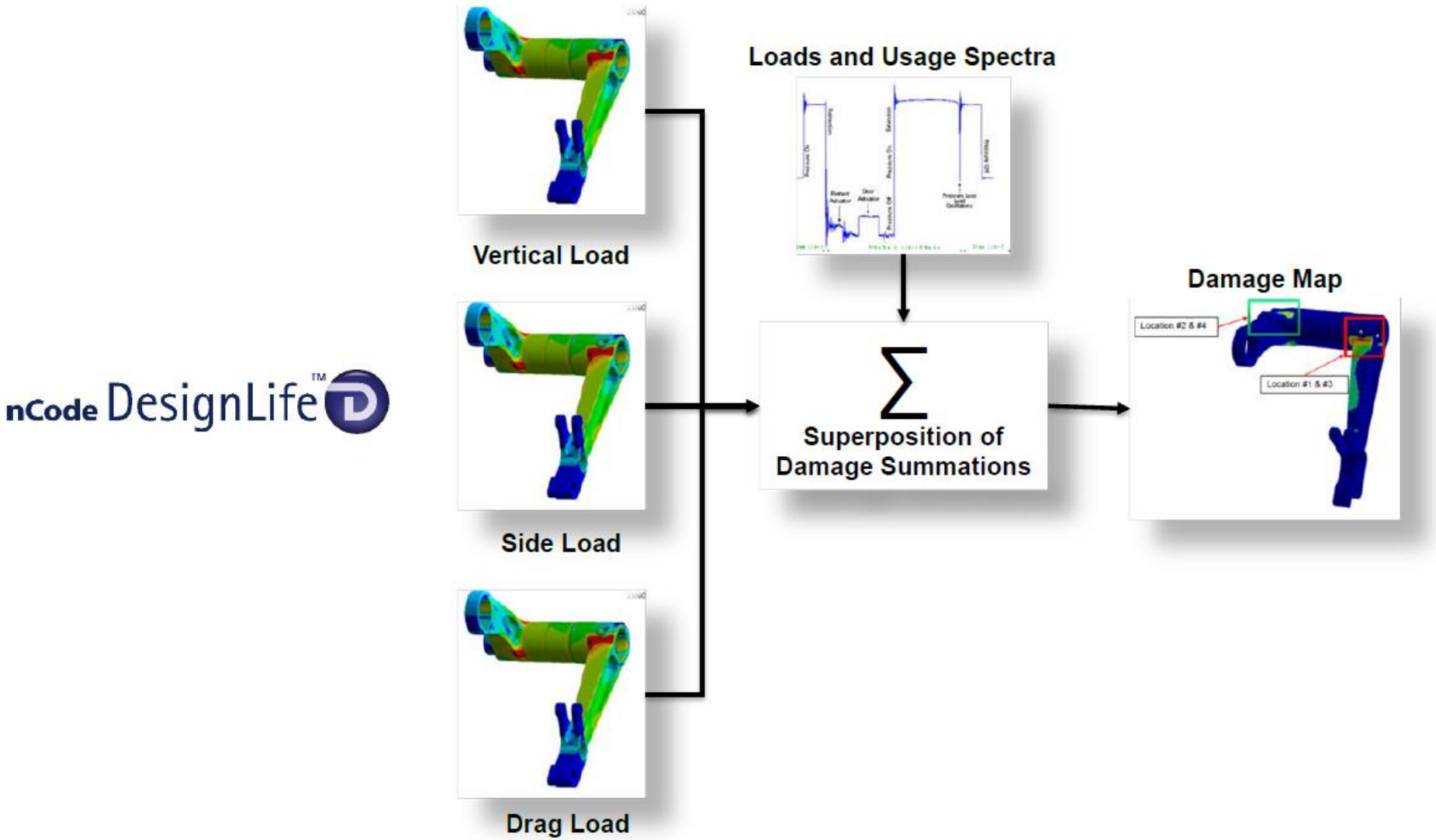
What is Considered in Landing Gear Repair and Design?

- **Static Strength**
  - Ultimate and Limit Stresses
  - Standard monotonic material properties
- **1G Residual Stresses**
  - Stress Corrosion Cracking Material Thresholds
- **Miners Fatigue Damage Accumulation**
  - Historically used stress life fatigue
  - Now strain life based fatigue
  - Can be problematic if sequencing is not considered

Contemporary Landing Gear Analysis



Advances in Safe Life Analysis



Agenda

1. USAF Landing Gear Systems

2. **HBK Advanced Materials Characterisation & Testing**
   - Application of K_{sur}
   - FEM Based Fatigue Analysis
   - Air Force Integration

3. Select Engineering Services

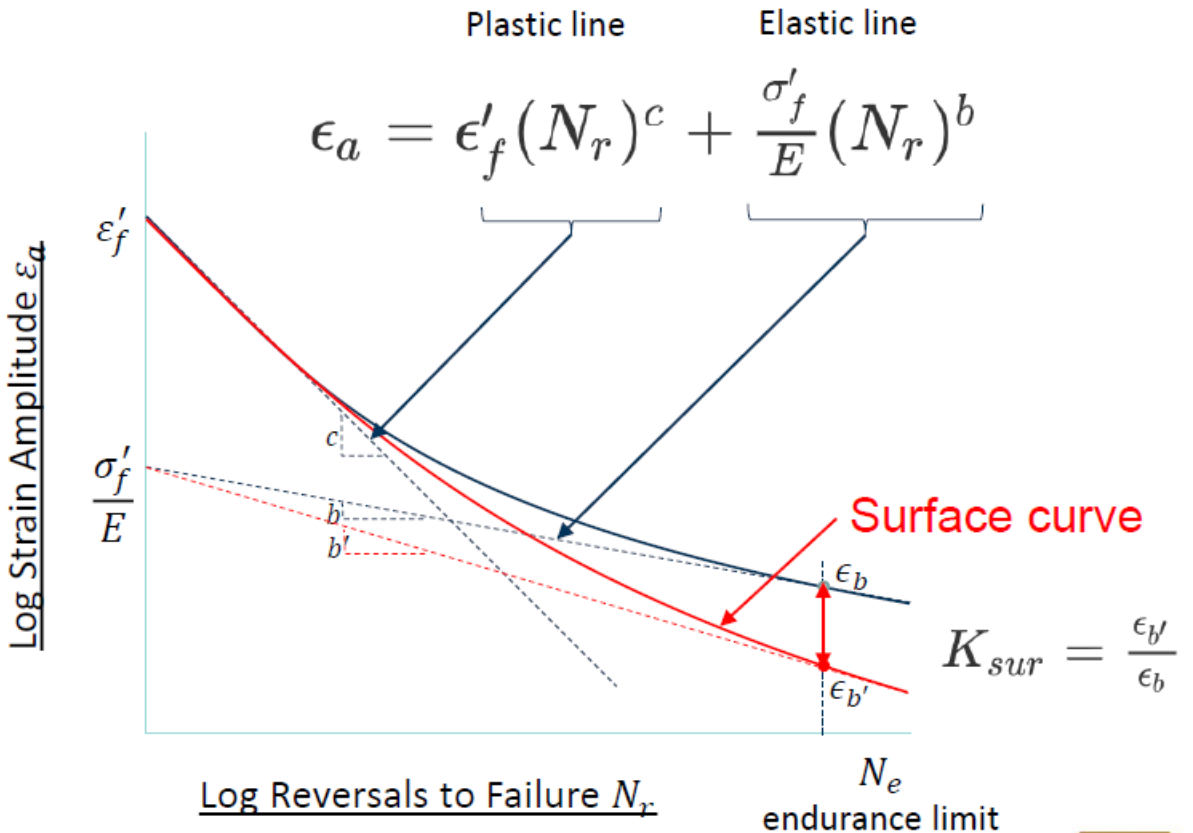
Application of K_{sur}

$$K_{sur} = K_{\text{treatment 1}} \times K_{\text{treatment 2}} \times K_{\text{roughness}} \times \dots$$

1. **Test & characterise baseline curve**
   - 25 point curve, Strain-control, fully-reversed (R=-1)
   - High & low-cycle fatigue

2. **Test under surface condition**
   - 12 point curve, Strain-control, fully-reversed
   - High-cycle fatigue only

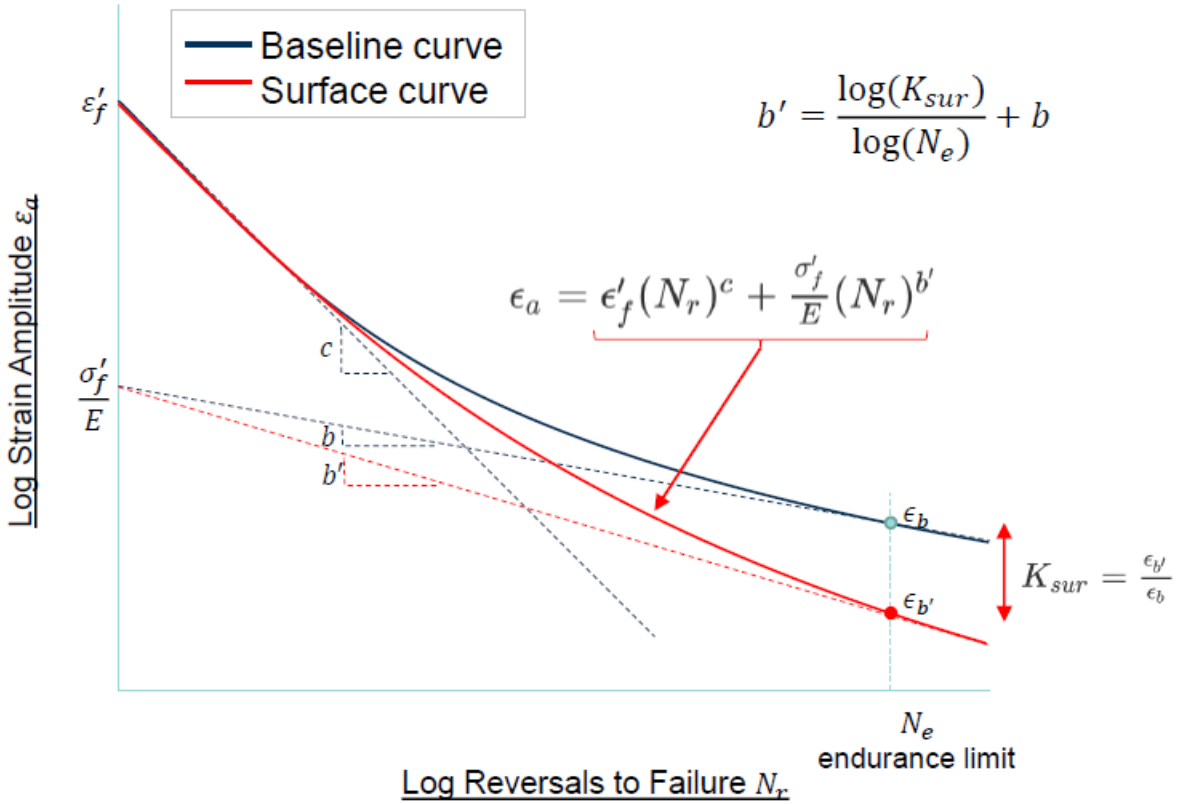
3. **Calculate K_{sur}**
   - Surface treatment effect quantified by a single parameter instead of deriving a new/independent 5-parameter curve
     - Reduced number of tests required to statistically characterize the surface treatment
     - Easier statistical comparisons
     - Compare different surface treatments on the same material
     - Compare same surface treatments on different materials
     - Sequentially combine surface treatment effects*
   - Assumes that surface treatment effects are greater at higher cycles



Application of K_{sur}

Application of K_{sur}

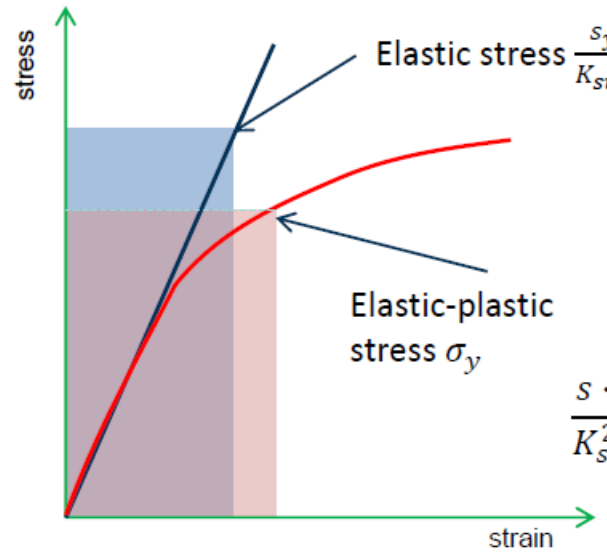
Adjusting the Elastic Line, b'



$$b' = \frac{\log(K_{sur})}{\log(N_e)} + b$$

$$\epsilon_a = \epsilon_f'(N_r)^c + \frac{\sigma_f'}{E}(N_r)^{b'}$$

Scaling the Applied Strain using Neuber



$$\frac{s \cdot e}{K_{sur}^2} = \frac{\sigma^2}{E} + \sigma\left(\frac{\sigma}{K'}\right)^{\frac{1}{n'}}$$

Elastic energy = elastic-plastic energy
or elastic area = plastic area

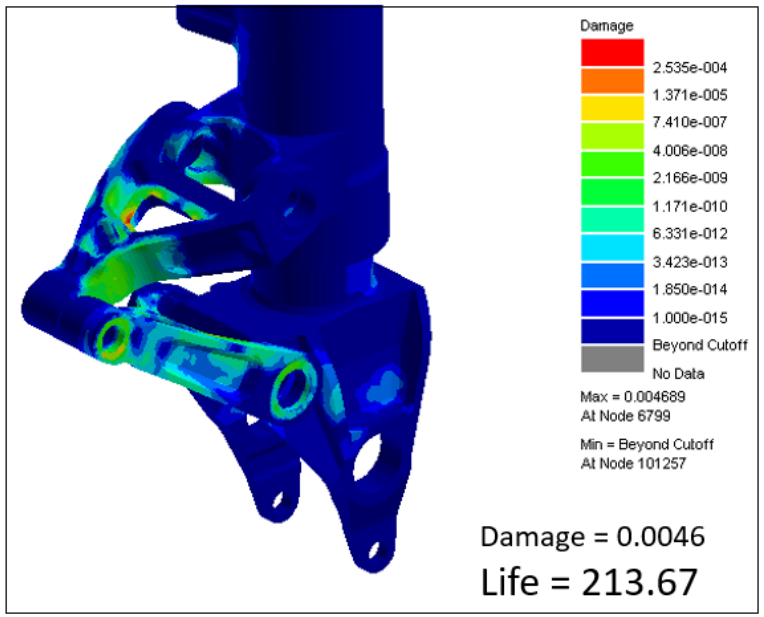
Neuber equivalence: $\frac{s_y \cdot e_y}{K_{sur}^2} = \sigma_y \cdot \epsilon_y$

FEM Based fatigue analysis

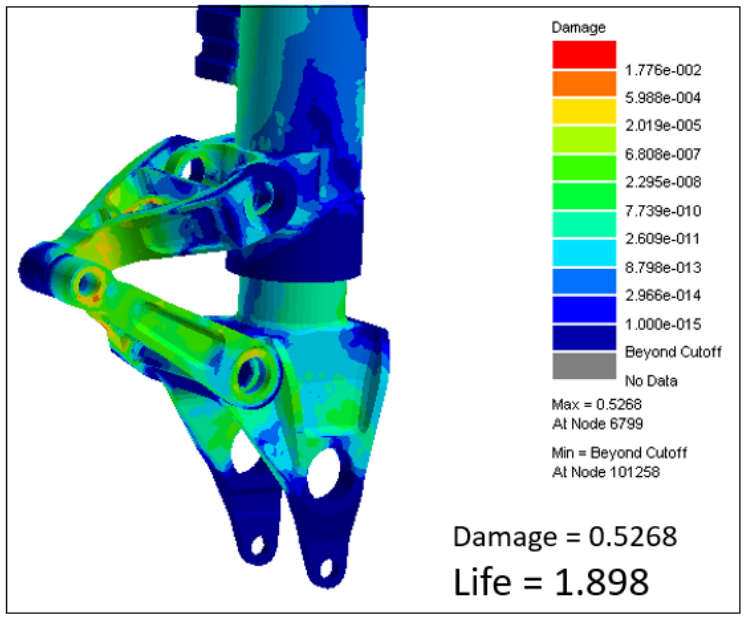
- nCode DesignLife Example - Results
  - Same applied loads for all analysis cases
  - K factor derived from collected test data
  - Additional analysis has included landing gear FEA model from actual USAF aircraft

Expected Life	Comparative units
Raw material	214
Surface effects	1.9
Design curve	0.7

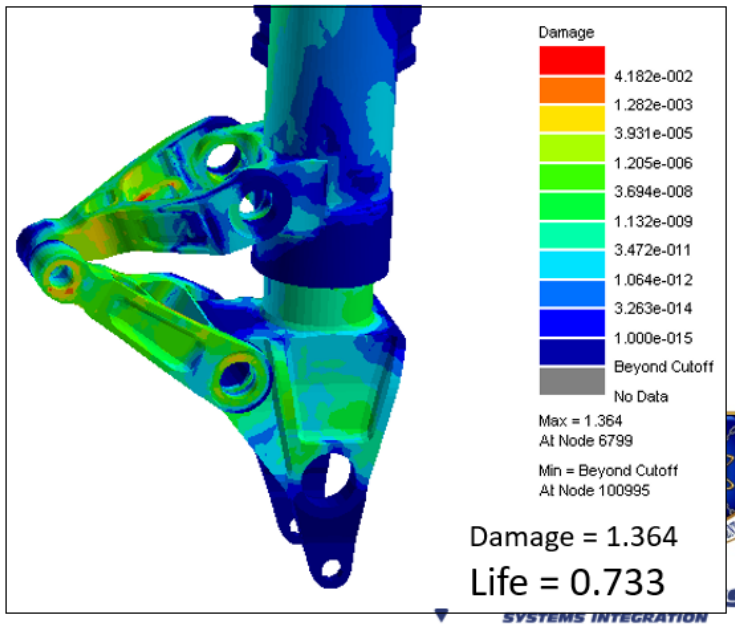
Baseline Curve Only *(No K_{sur} Applied)*
50% Certainty of Survival / 50% Confidence



K_{sur} Applied to Baseline Curve
50% Certainty of Survival / 50% Confidence



K_{sur} Applied to Design Curve
97.7% Certainty of Survival / 95% Confidence



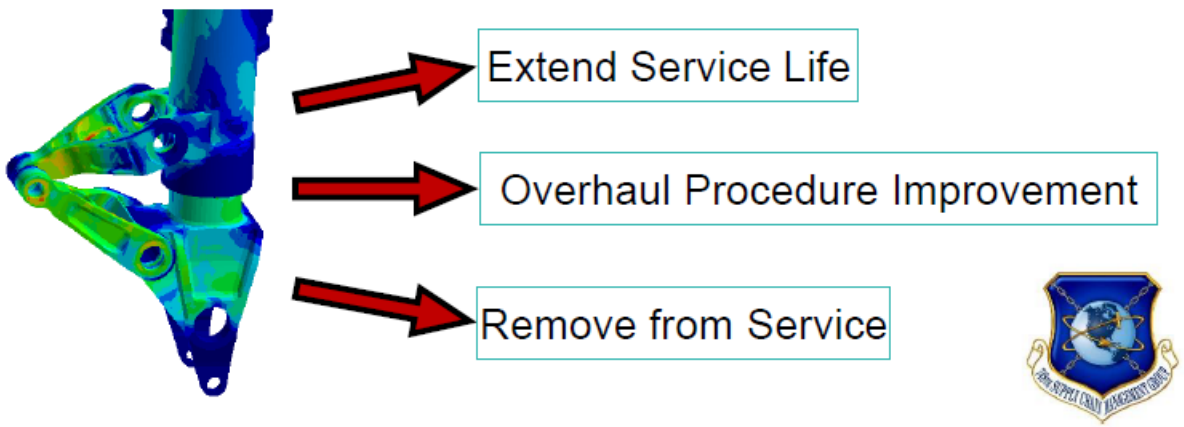
Air Force Integration

- Principal project outcome:
  "***increased fidelity in USAF landing gear fatigue models***"
  - MAPA Tool
  - K factor database with streamlined nCode user interface
  - Knowledgebase of fatigue analysis curves, data sets, methods, assumptions, etc.

- ✓ Mitigate landing gear life extension risk
- ✓ Improve decisions for removal of landing gear components from service
- ✓ Potential improvements to repetitive overhaul processes

- Current Testing Status
  - ✓ Baseline ε-N curves (polished specimens) for 3 materials
  - ✓ 9 batches of surface treated specimens tested
  - ✓ Funding secured to test several additional surface treatments

- MAPA Tool development (K factors, user interface, knowledgebase)
- Demonstrate K factors in USAF landing gear fatigue models



GENERAL ATOMICS SYSTEMS INTEGRATION

SES Select Engineering Services

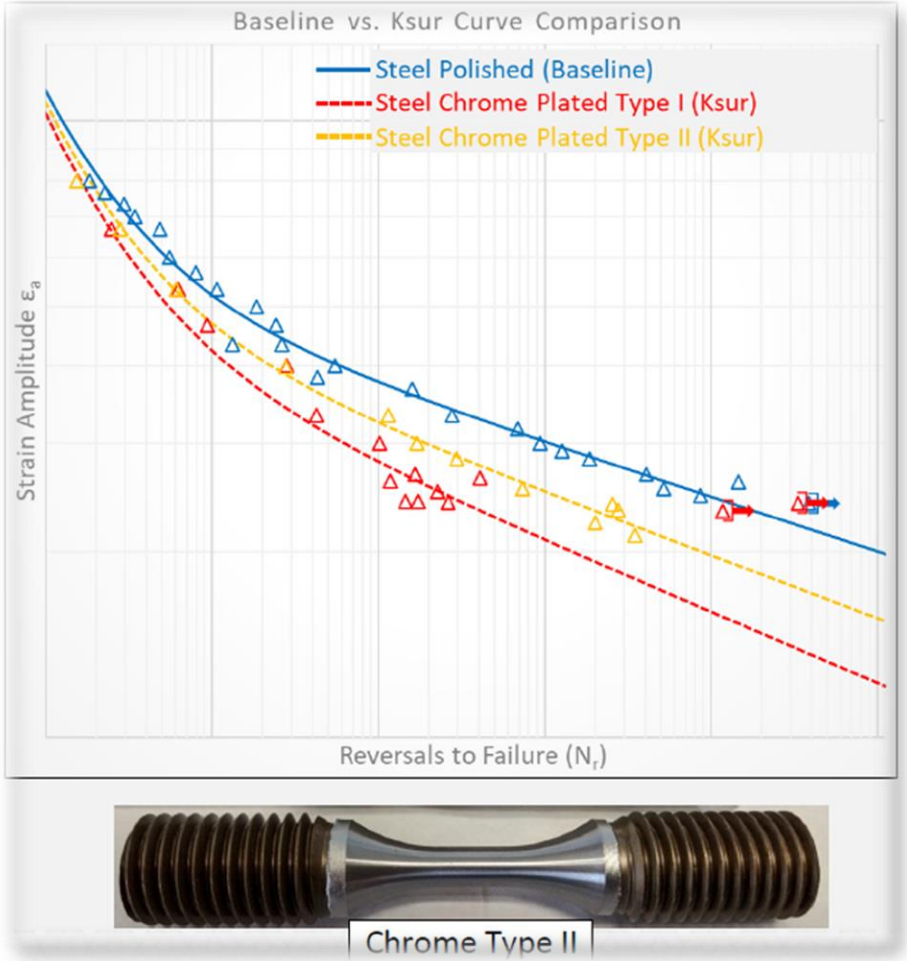
HBK HOTTINGER BRÜEL & KJÆR

Agenda

1. USAF Landing Gear Systems

2. HBK Advanced Materials Characterisation & Testing

3. **Select Engineering Services**
   - Project Background and Significance
   - Tested Results – Chrome on Steel
   - MAPA - Material Assessment and Predictive Analysis
   - MAPA Data Manager
   - MAPA Simulation Manager



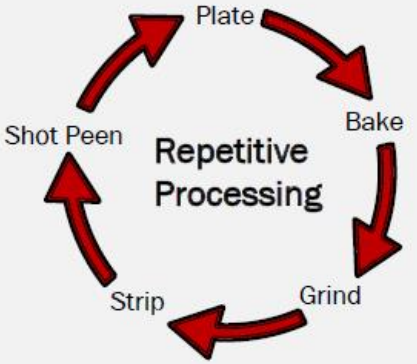
PROJECT BACKGROUND AND SIGNIFICANCE

SES
Select Engineering Services

- *Landing Gear Surface Treatments*
  - *Affected Surface Material Properties*
    - *Microstructure*
    - *Roughness*
    - *Residual Stresses*
  - *Coatings Stripped/Re-Applied*
    - *May be repeated several times*
    - *Indeterminate number of overhauls*
    - *Multiple coating options and specs*
  - *Known Detrimental Effects*
    - *Not considered in legacy USAF design*


Electroplating[4]


Shot Peening[3]




Heat Treatment[1]

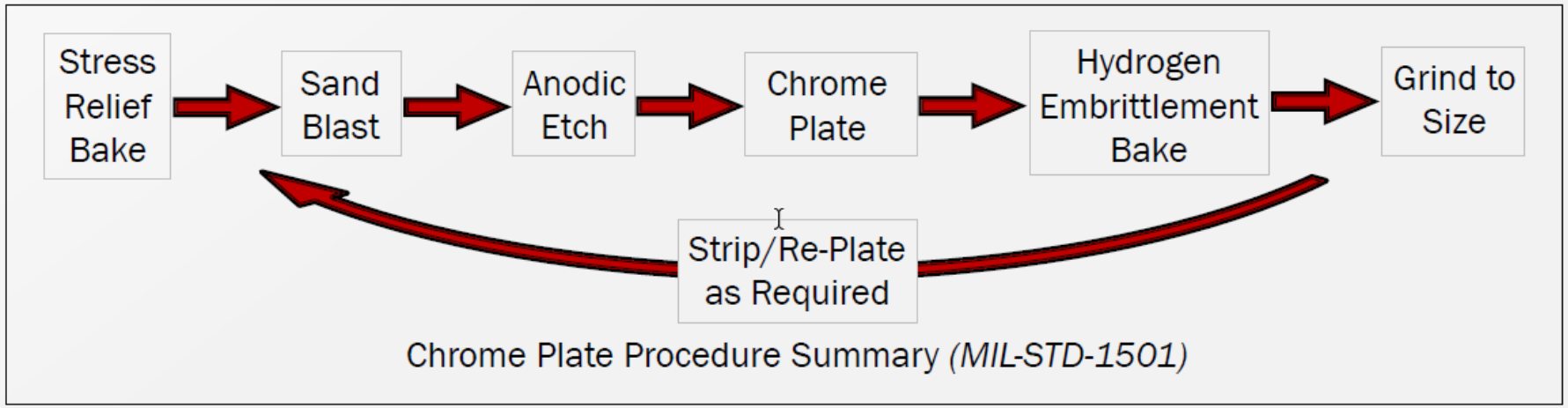

Grinding[2]

[1]http://www.nationalbronze.com/News/nickel-aluminum-bronze-for-landing-gear-bushings/
[2]https://www.danobatgrinding.com/en/aerospace-landing-gear-struts-machining
[3]https://www.wheelabratorgroup.com/en-us/my-application/application-by-industry/aerospace/landing-gear-preparation
[4]https://www.hydro-platers.com/

PROJECT BACKGROUND AND SIGNIFICANCE

SES
Select Engineering Services

- ***Surface Treatment Procedures***
  - ***Based on Military Standards***
  - ***USAF dictates specific landing gear overhaul parameters***
  - ***Substantial number of variables to control/consider***

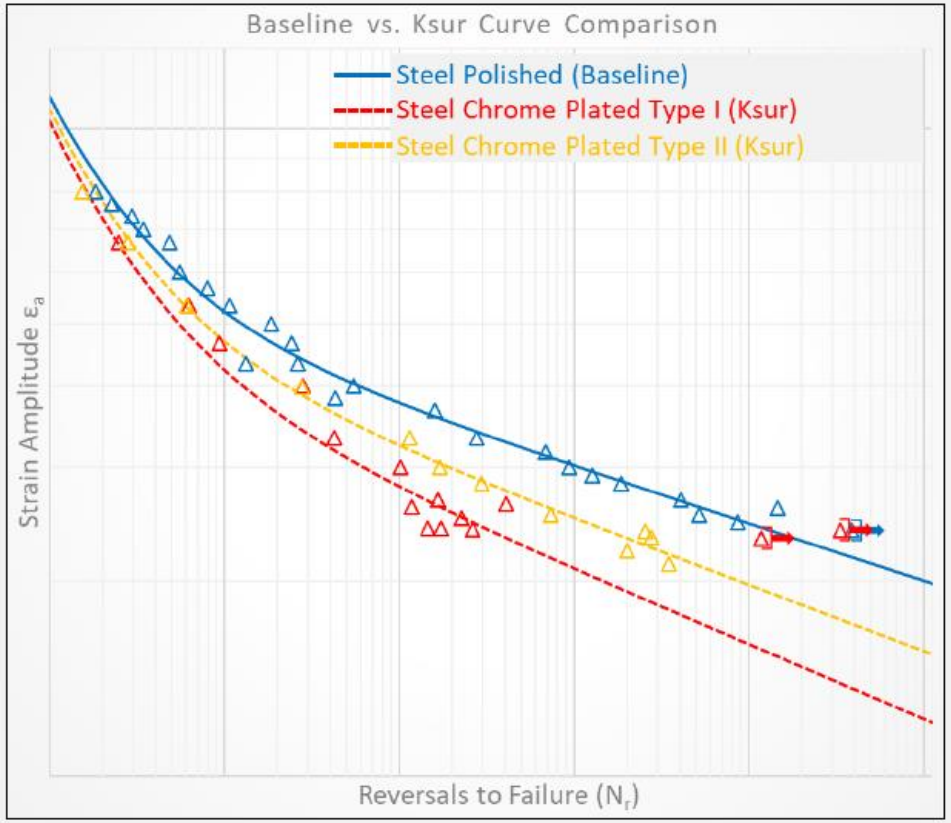


Chrome Plate Procedure Summary *(MIL-STD-1501)*

TESTED RESULTS
CHROME ON STEEL

SES
Select Engineering Services

- *Chrome Type I (plated to size)*
  - *Substantial fatigue life reduction*
  - *Shot peen effective in restoring fatigue performance (not shown in plot)*
- *Chrome Type II (ground to size)*
  - *Significant fatigue life reduction (less detrimental than Type I)*
  - *Shot peen effective in restoring fatigue performance (not shown in plot)*
  - *Same plating thickness as Electrolytic Nickel specimens*
- *Chrome Type II - Strip/Re-Plate at Half-Life*
  - *Tested with shot peen only*
  - *No significant fatigue performance reduction*

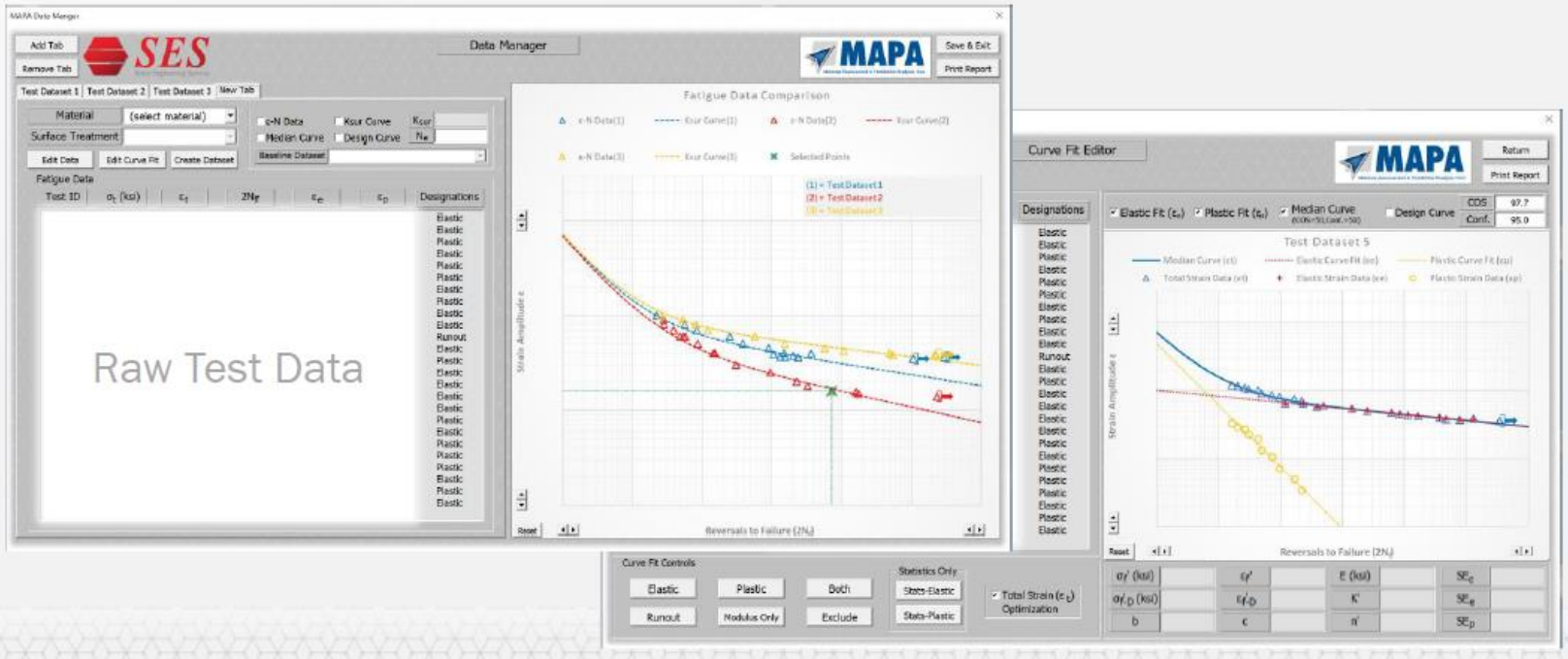



Chrome Type I


Chrome Type II

MAPA DATA MANAGER

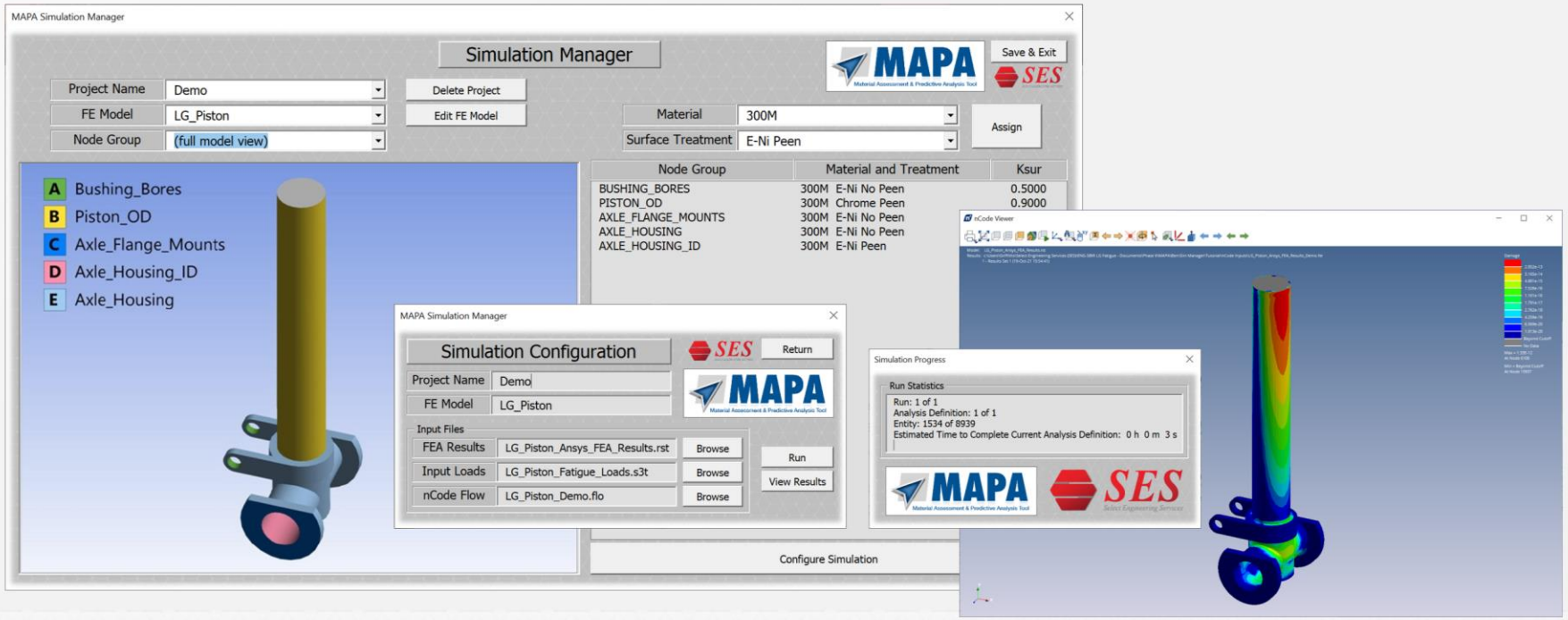
- *Rapid comparisons of raw data and fitted curves*
- *Adjust curve fit designations and statistics*
- *Generate parameters for input to nCode*
- *Show/hide plots and print reports*
- *Directed user inputs for raw fatigue data*



MAPA SIMULATION MANAGER

SES Select Engineering Services

- *Generate node group files in ANSYS for input to nCode*
  - *Allows use of solid model geometry selection tools in ANSYS*
- *Automate material property assignment and bill of materials*
- *Export configuration/material assignments for use in nCode*



Conclusions

- Surface treatment effects have been tested and quantified for multiple material and surface treatment combinations.

- These have shown that the surface treatment factor, K_{sur} method, can be successfully applied with the strain-life fatigue method.

- For USAF, the positive outcomes and conclusions include:
  1. Increased confidence in life extension for aging aircraft landing gear components.
  2. The timely removal of landing gear components from service to decrease the risk of failure.
  3. The potential for improvements to repetitive overhaul processes that will reduce their negative impact on fatigue life.

References

1. United States Air Force
   - Clark, A. (2021),
     An introduction to the requirements for
     safe-life of landing gear for aging aircraft
     through overhaul and maintenance processes,
     https://www.hbkworld.com/en/knowledge/events/technology-days/2021-hbk-technology-days

2. Select Engineering Services
   - Griffiths, B. (2021),
     Tools and methods for landing gear
     fatigue analysis with surface treatment effects,
     https://www.hbkworld.com/en/knowledge/events/technology-days/2021-hbk-technology-days

3. HOTTINGER BRÜEL & KJÆR
   - Halfpenny, A. (2021),
     Surface treatment effects in fatigue
     analysis of landing gear materials,
     https://e-i-s.org.uk/fatigue-2021

4. ASIP 2019 Proceedings – paper and presentation
   - Clark, Griffiths, Halfpenny, et al
   - http://www.arctosmeetings.com/agenda/asip/2019/agenda.html

Thank You

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Andrew Clark, USAF

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*on a day-to-day basis or as part of **more intensive overhauls** that extend an aircraft’s life …”*

Surface treatments have known detrimental effects on fatigue life but were not considered in legacy USAF design, this work is characterising those detrimental effects …

Questions

HBK
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