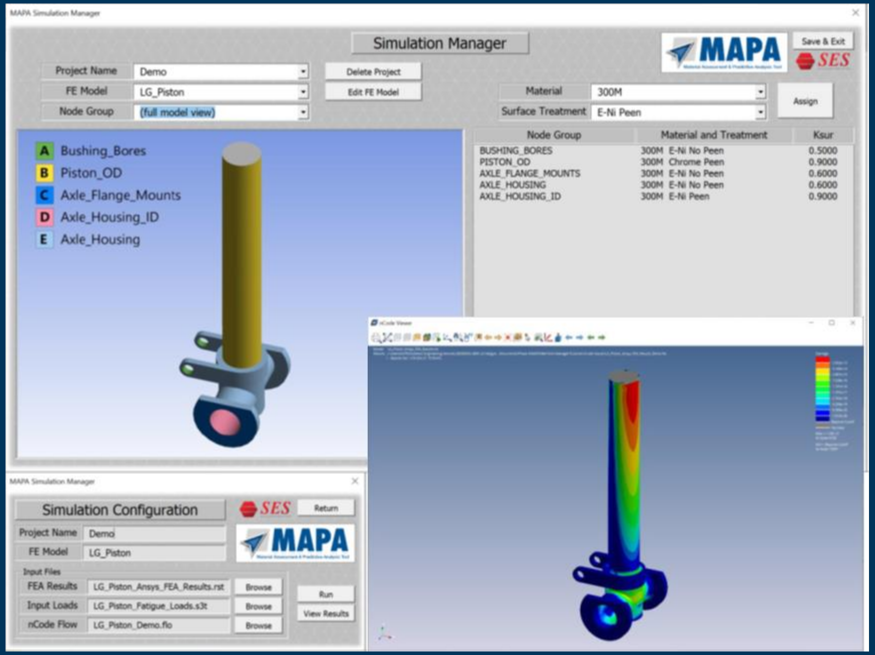
Virtual Seminar Series – Tuesday 2, 9, 16 November



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

Presented by Mr. Ben Griffiths
Chief Engineer
Select Engineering Services

Tuesday, November 9, 2021

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

Abstract

Landing gear manufacturing and overhaul/maintenance processes alter surface material properties that influence fatigue life. The effect of these processes was not accurately accounted for in legacy United States Air Force (USAF) landing gear designs. As aging aircraft in the USAF fleet continue to be pushed beyond their originally intended service life, it has become increasingly more critical to characterize specific surface processing conditions. For this reason, Select Engineering Services (SES), General Atomics Systems Integration (GA-SI), and the HBK Advanced Materials Characterization & Test (AMCT) Facility are conducting research/testing to develop tools and methods that incorporate surface treatment effects in USAF landing gear fatigue models.

Surface treatment factors (k factors) are used in nCode DesignLife software to accurately debit strain-life analysis curves and account for material surface conditions. SES has collected 24 datasets to derive 19 k factors for 3 common landing gear materials. In order to facilitate efficient data management and k factor application in nCode DesignLife simulations, SES has developed the Material Assessment and Predictive Analysis (MAPA) tool. The purpose of this presentation is to provide an overview of material and surface treatment characterizations, demonstrate capabilities of the MAPA tool, and establish the significance of completed research and development.

About the presenter, Mr. Ben Griffiths, Select Engineering Services

Ben Griffiths has a Masters degree in Mechanical Engineering from Utah State University and is a licensed Professional Engineer in the state of Utah. He has 9 years of experience conducting research and development with an emphasis on materials testing and analysis. Some of the research projects he has worked on include:

- Fatigue testing/analysis of landing gear materials with various surface treatments
- Full scale crash testing of composite towers using surrogate aircraft wing sections
- Electrically conductive coating qualification testing
- Welding of thick section Grade 91 steel to study Type IV creep rupture

Mr. Griffiths is representing Select Engineering Services (SES) which is an employee owned small business operating out of the state of Utah. SES primarily focuses on engineering and analytical services for the United States Air Force (USAF) and other DoD agencies.

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TOOLS AND METHODS FOR LANDING GEAR FATIGUE ANALYSIS WITH SURFACE TREATMENT EFFECTS

HBK Prenscia Technology Days 2021

KEY CONTRIBUTORS

- *USAF 417th SCMS/GUEA Landing Gear Office*
  - Andrew Clark, Lead Engineer, Landing Gear Systems
- *HBK Prenscia Advanced Materials Characterization & Test Facility*
  - Dr. Andrew Halfpenny, Director of Technology
  - Dr. Michelle Hill, Head of Materials Testing
- *General Atomics - Systems Integration*
  - Ben Madsen, Lead Analysis Engineer
- *Select Engineering Services*
  - Ben Griffiths, Chief Mechanical Engineer

AGENDA

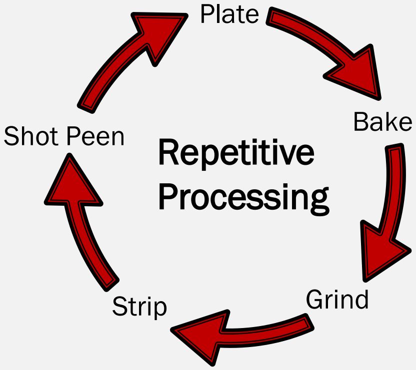
- ***Introduction***
  - ***Project Background and Significance***
- ***Methods***
  - ***Strain-Life Testing***
  - ***Calculations***
  - ***Tested Results***
  - ***MAPA Data Manager***
  - ***MAPA Simulation Manager***
- ***Ongoing Efforts***

PROJECT BACKGROUND AND SIGNIFICANCE

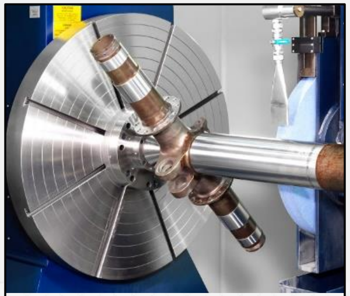
- ***Landing Gear Surface Treatments***
  - ***Affected Surface Material Properties***
    - ***Microstructure***
    - ***Roughness***
    - ***Residual Stresses***
  - ***Coatings Stripped/Re-Applied***
    - ***May be repeated several times***
    - ***Indeterminate number of overhauls***
    - ***Multiple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


Electroplating[4]


Shot Peening[3]

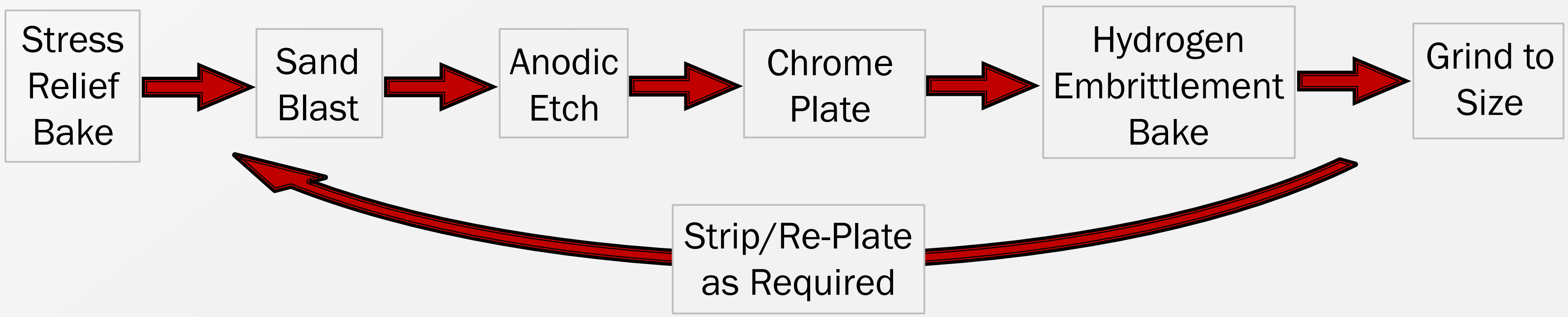



Heat Treatment[1]


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/

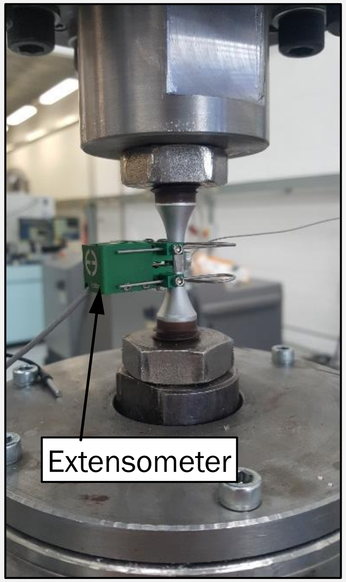
- *Surface Treatment Procedures*
  - *Based on Military Standards*
  - *USAF dictates specific landing gear overhaul parameters*
  - *Substantial number of variables to control/consider*



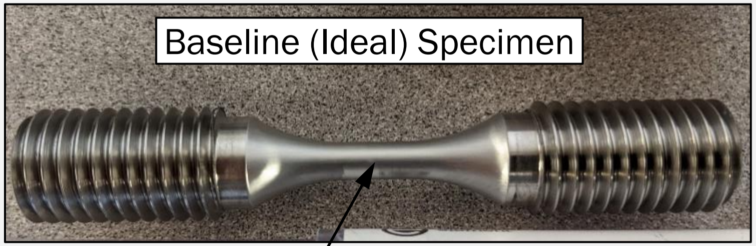
Chrome Plate Procedure Summary *(MIL-STD-1501)*

STRAIN-LIFE TESTING

- *Conducted at the AMCT Facility (HBK)*
  - *Fully reversed uniaxial strain – ASTM E606*
  - *Strain-control maintained for entire test*
  - *Wood's metal pot for specimen alignment*
- *Specimen Fabrication*
  - *Baseline (ideal) specimens longitudinally polished*
  - *Surface treated specimens fabricated to USAF landing gear specs*



Fatigue Test Setup



Longitudinal Polish

DATA COLLECTION

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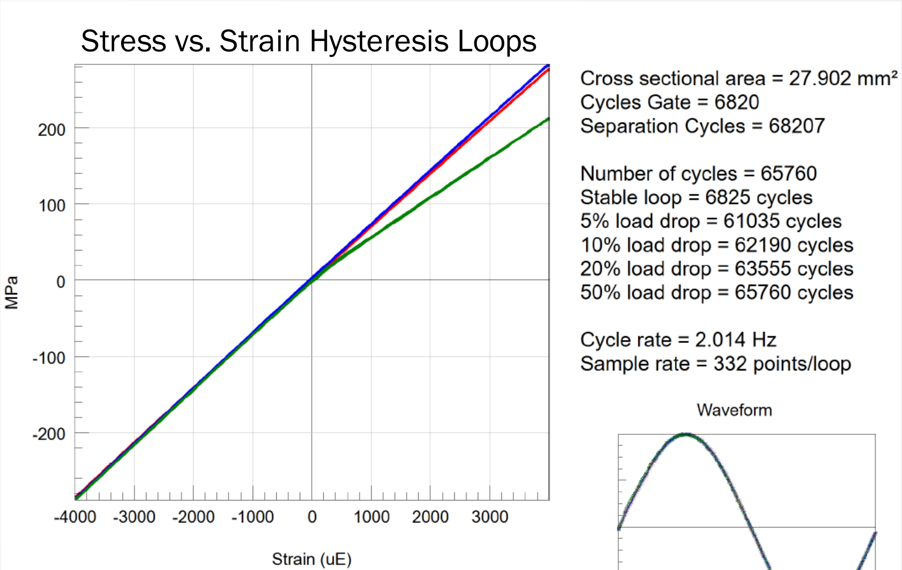
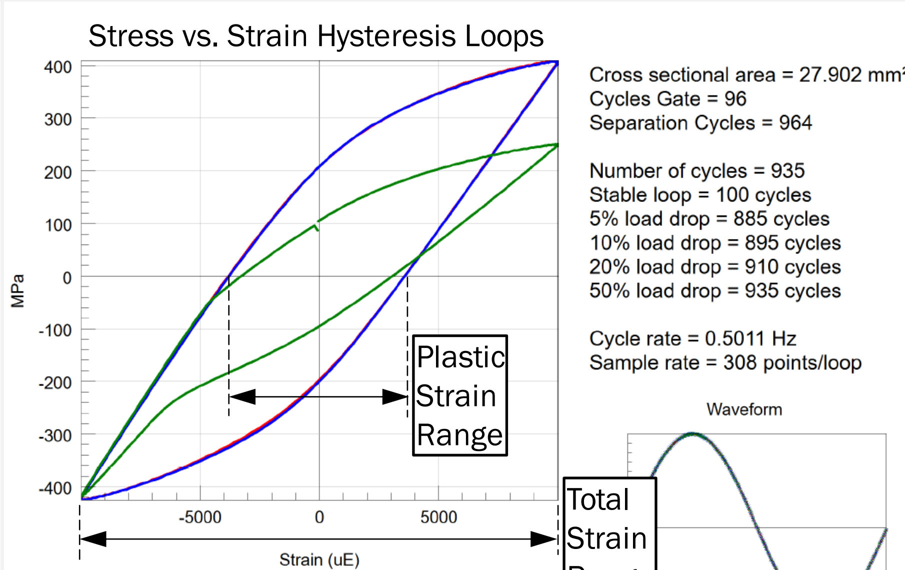
- ***Stress-Strain Hysteresis Loops***
  - ***Divided into elastic and plastic strains***
- ***Cycles to Failure (20% load drop)***

$$Elastic\ Strain\ Range = Total\ Strain\ Range - Plastic\ Strain\ Range$$



..	Cycle Nu...	Total Stress	Total Strain	Elastic Str...	Plastic Str...
red	105	562.8	7986	7930	56.27
blue	3.29E4	571.2	7996	7943	53.02
green	6.356E4	501.2	7992	7991	0.6898



..	Cycle Nu...	Total Stress	Total Strain	Elastic Str...	Plastic Str...
red	100	833.7	1.997E4	1.271E4	7268
blue	470	833.9	1.999E4	1.278E4	7208
green	910	669.8	1.998E4	1.381E4	6175

STRAIN-LIFE CALCULATIONS

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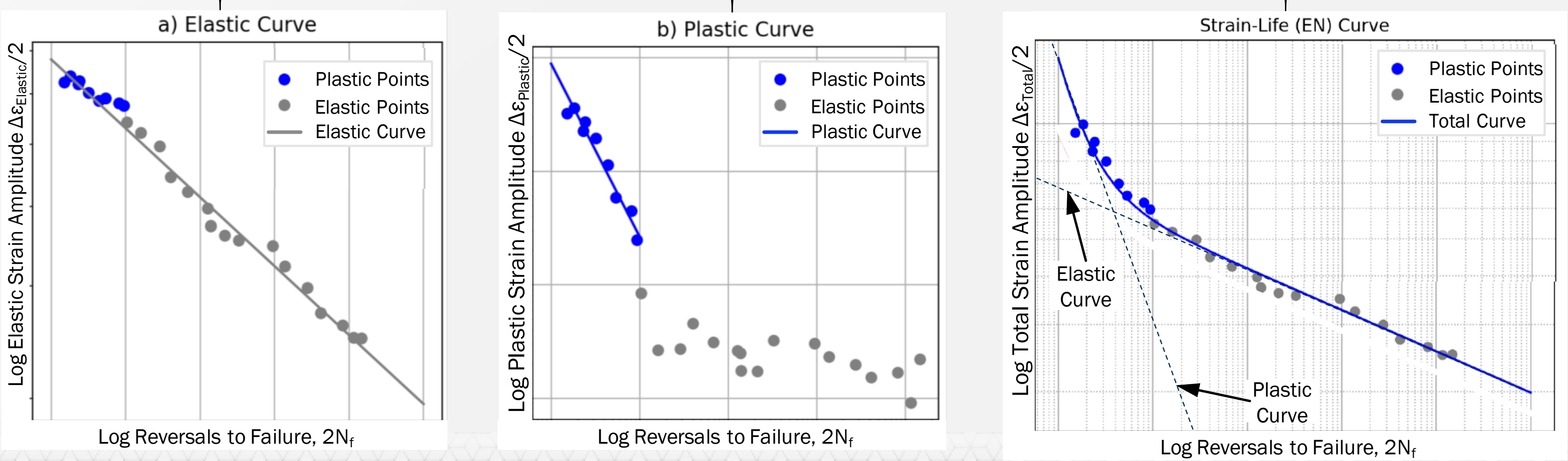
- ***Curve Fitting: Coffin-Manson-Basquin***
  - ***Separate log-linear regression for elastic and plastic curves***
  - ***Sum elastic and plastic curves for total strain-life curve***
  - ***Secondary optimization of total strain curve***
    - ***Minimize sum of squared residuals by modifying σ'_f and ε'_f***

$$\underbrace{\frac{\Delta\varepsilon_{Elastic}}{2} = \frac{\sigma'_f}{E}(2N_f)^b}$$

$$\underbrace{\frac{\Delta\varepsilon_{Plastic}}{2} = \varepsilon'_f(2N_f)^c}$$

$$\underbrace{\frac{\Delta\varepsilon_{Total}}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c}$$



STRAIN-LIFE CALCULATIONS

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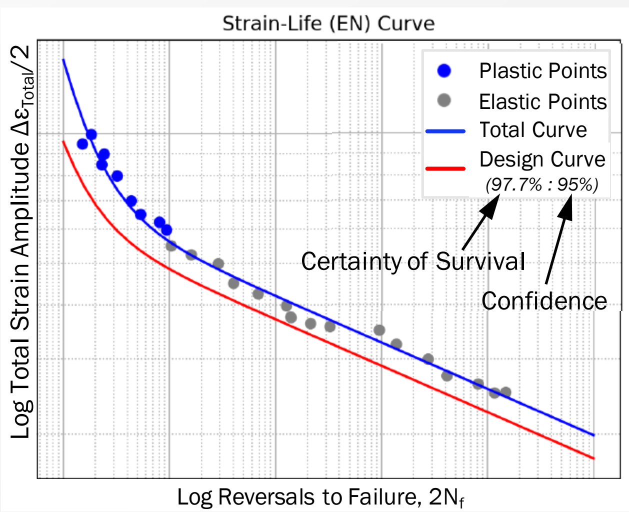
- ***Design Curve***
  - ***Based on selected Certainty of Survival and Confidence Level***
  - ***Justifiable margin of safety for design***



<u>Design Curve Equation</u>

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E} 10^{k_{U\_Elastic} * SE_{elastic}} (2N_f)^b + \varepsilon_f' 10^{k_{U\_Plastic} * SE_{Plastic}} (2N_f)^c$$

$$k_{U\_(Elastic\ or\ Plastic)} = \frac{z_\rho + \frac{z_\gamma}{\sqrt{n}}\sqrt{1 - \frac{z_\gamma^2}{2(n-1)} + \frac{n z_\rho^2}{2(n-1)}}}{1 - \frac{z_\gamma^2}{2(n-1)}}$$

z_ρ = inverse cumulative normal for specified reliability statistic *(certainty of survival)*
z_γ = inverse cumulative normal for specified confidence interval
n = number of data points used to fit the curve *(elastic or plastic)*
SE = standard error of log(strain) *(elastic or plastic)*

SURFACE TREATMENT FACTORS – K_{SUR} METHOD

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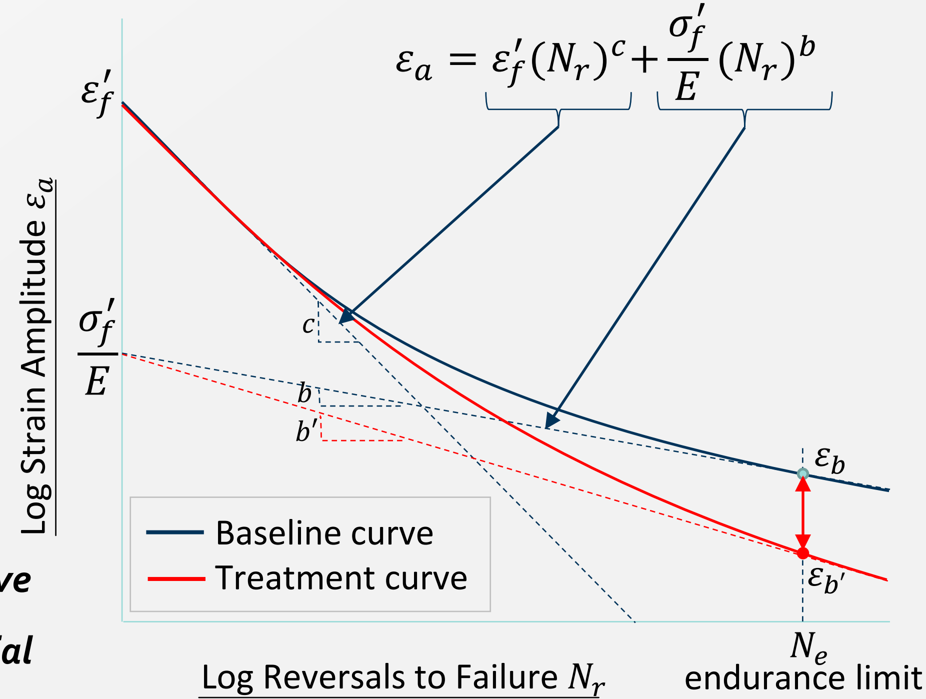
- ***Baseline curve (5 parameters)***
  - *25 data points, fully reversed strain (R=-1)*
  - *High & low-cycle characterization*
- ***Surface treatment test data***
  - *12 data points, fully reversed strain (R=-1)*
  - *Focused on high-cycle fatigue*
- ***Attributes of K_{sur}***
  - *Single parameter treatment characterization*
  - *Similar statistical significance to 25-point curve*
  - *Compare different treatments on same material*
  - *Compare same treatments on different material*
  - *Assumes treatment effects greater at high cycles*

$$\varepsilon_a = \underbrace{\varepsilon_f'(N_r)^c}_{\text{Plastic line}} + \underbrace{\frac{\sigma_f'}{E}(N_r)^b}_{\text{Elastic line}}$$



$$K_{sur} = \frac{\varepsilon_{b'}}{\varepsilon_b} = (N_e)^{b'-b}$$

K_{SUR} NUMERICAL CALCULATIONS

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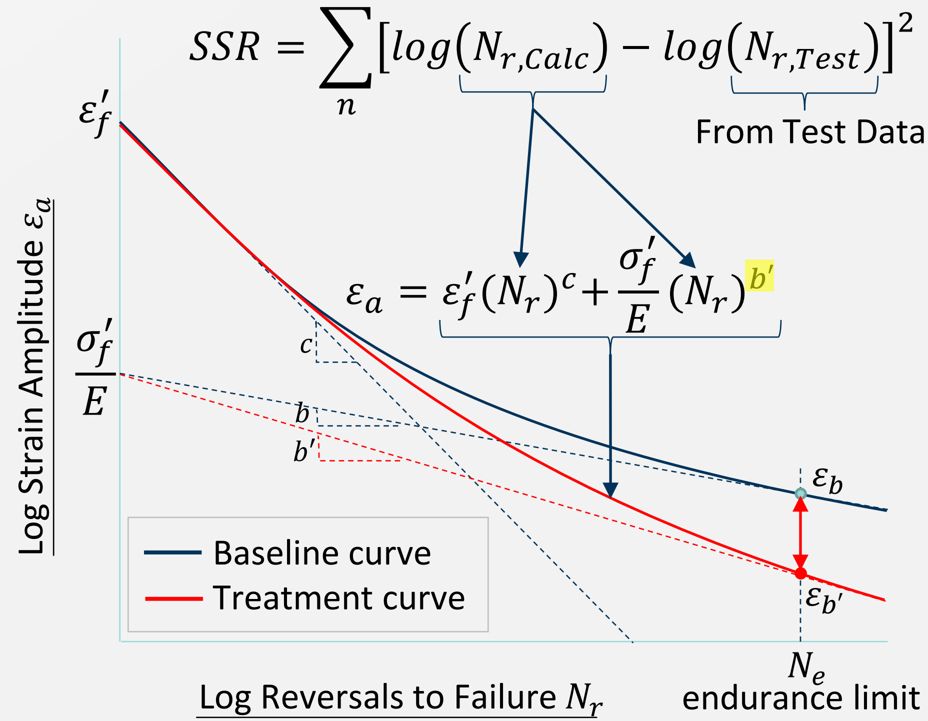
- ***K_{sur} is a function of b′, b, and N_e*** $\longrightarrow$ $K_{sur} = (N_e)^{b'-b}$
  - ***b′ - slope of elastic line for surface treatment curve***
  - ***b - slope of elastic line calculated with baseline (ideal) curve***
  - ***N_e - selected endurance limit***
    - *Does not affect surface treatment curve*
- ***b′ calculated iteratively to minimize sum of squared residuals (SSR)***
  - ***Cycles to failure considered dependent variable***
  - ***Equation for SSR must be solved using numerical methods***



TESTED RESULTS
SHOT PEEN ON POLISHED STEEL

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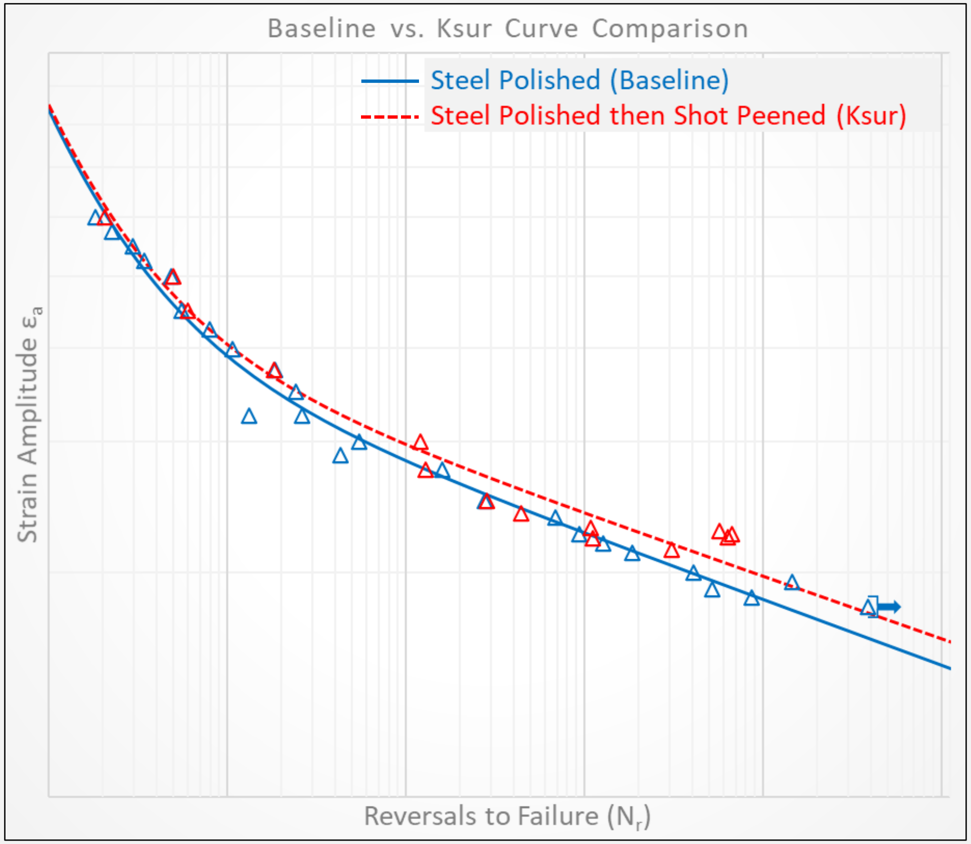
- ***Longitudinally Polished then Shot Peened***
  - *Slight increase in high-cycle fatigue life*
  - *Negligible benefit to the endurance behavior*
  - *Overall benefit to fatigue performance offset by increase in statistical scatter*



Polished then Shot Peened

TESTED RESULTS NICKEL ON STEEL

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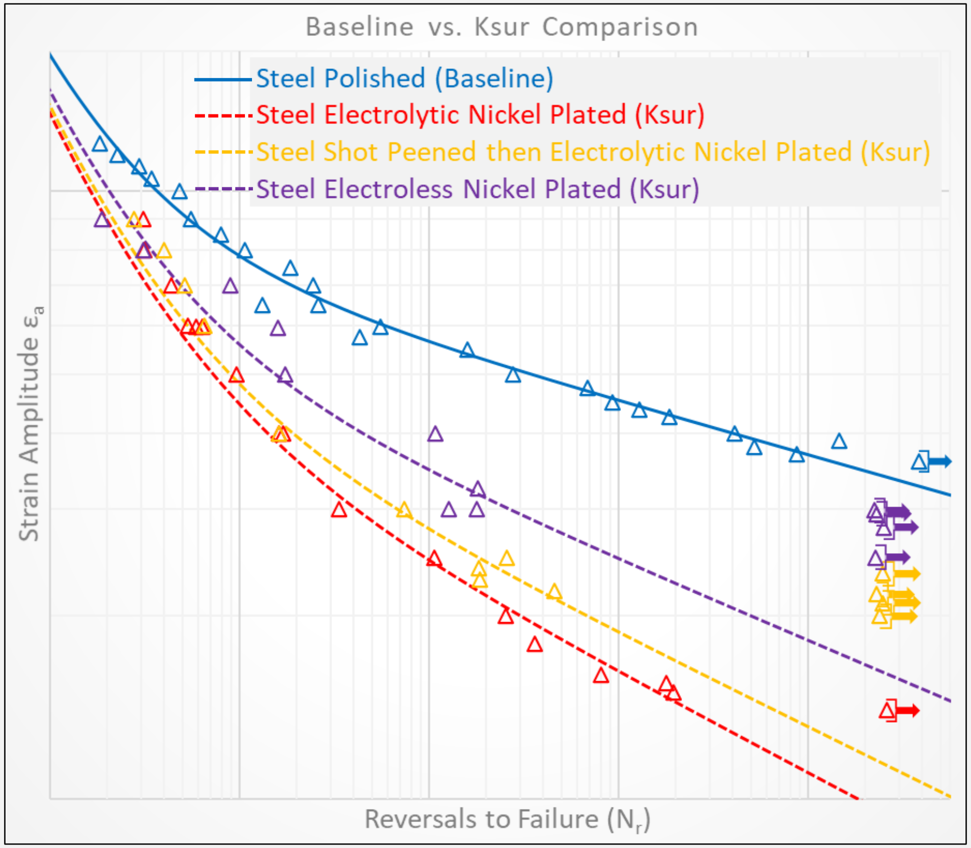
- ***Electrolytic Nickel (ground to size)***
  - *Very severe fatigue life reduction*
  - *Shot peen not effective in restoring fatigue performance*
- ***Electroless Nickel (plated to size)***
  - *Substantial fatigue life reduction*
  - *Shot peen effective in restoring fatigue performance (not shown in plot)*



Electrolytic Nickel

Electroless Nickel

TESTED RESULTS CHROME ON STEEL

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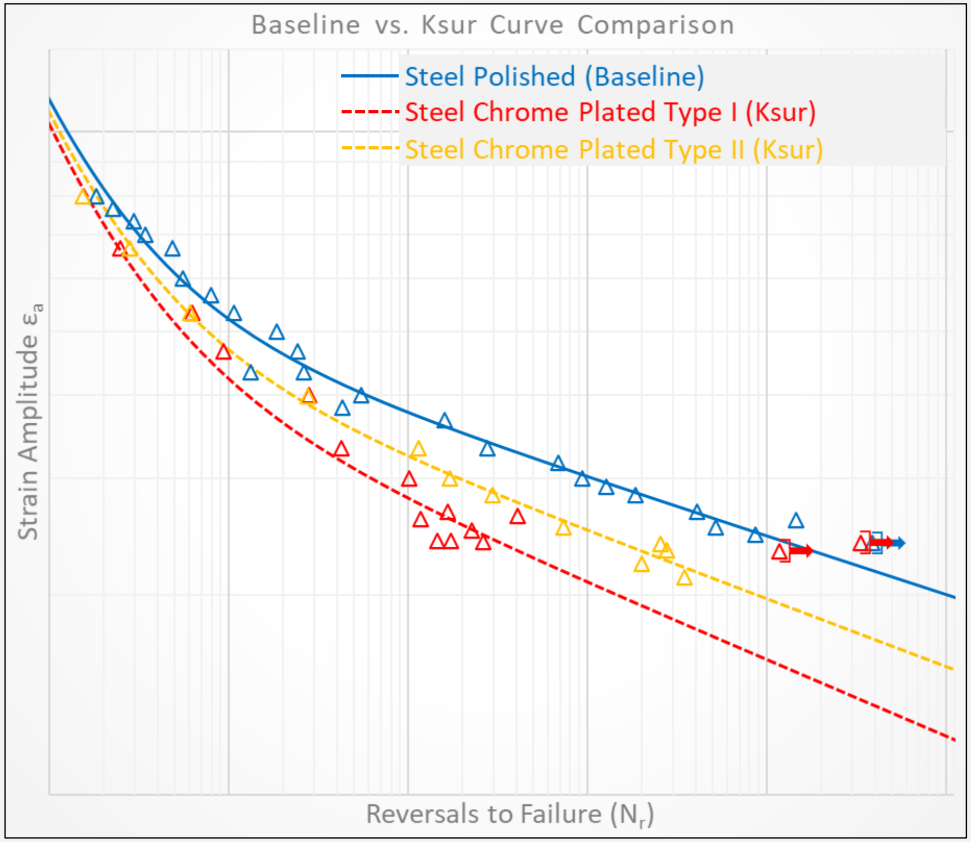
- *Chrome Type I (plated to size)*
  - *Substantial fatigue life reduction*
  - *Shot peen effective in restoring fatigue performance (not shown in plot)*
- *Chrome Type II (ground to size)*
  - *Significant fatigue life reduction (less detrimental than Type I)*
  - *Shot peen effective in restoring 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*

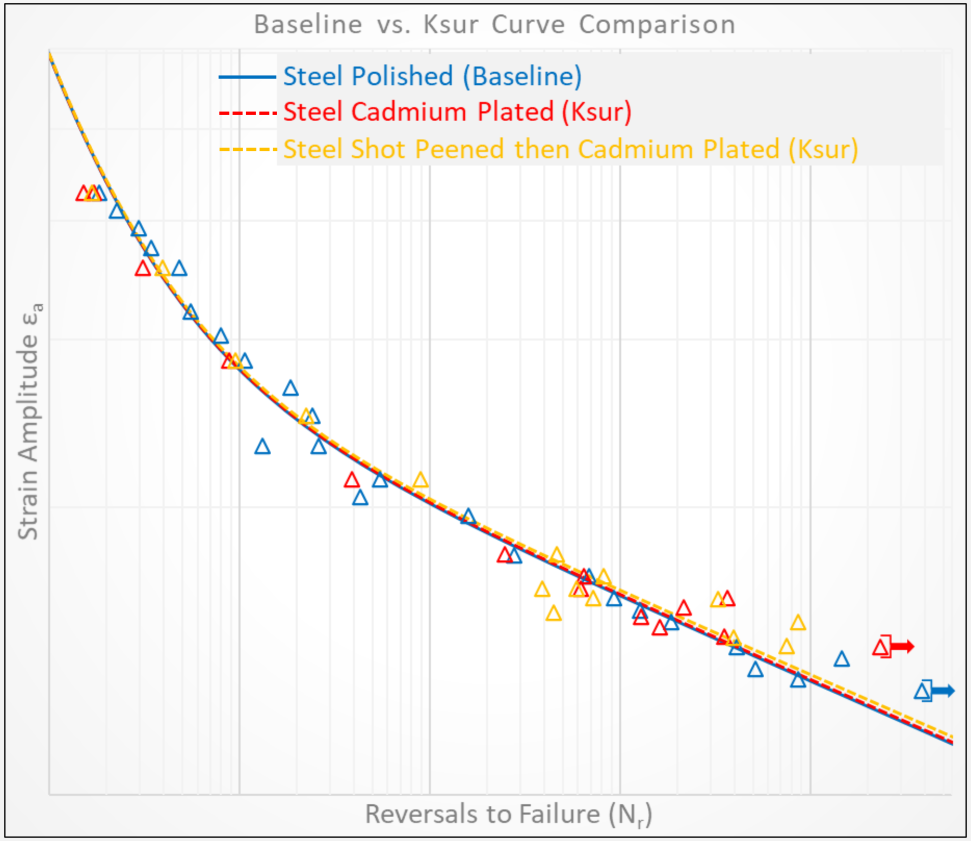


Chrome Type I

Chrome Type II

TESTED RESULTS CADMIUM ON STEEL

- *Cadmium Plate*
  - *No significant detrimental effect on fatigue performance*
  - *Shot peen offers no beneficial effect on fatigue performance*
  - *Fitted curves for Cadmium nearly identical to Baseline (ideal) curve*



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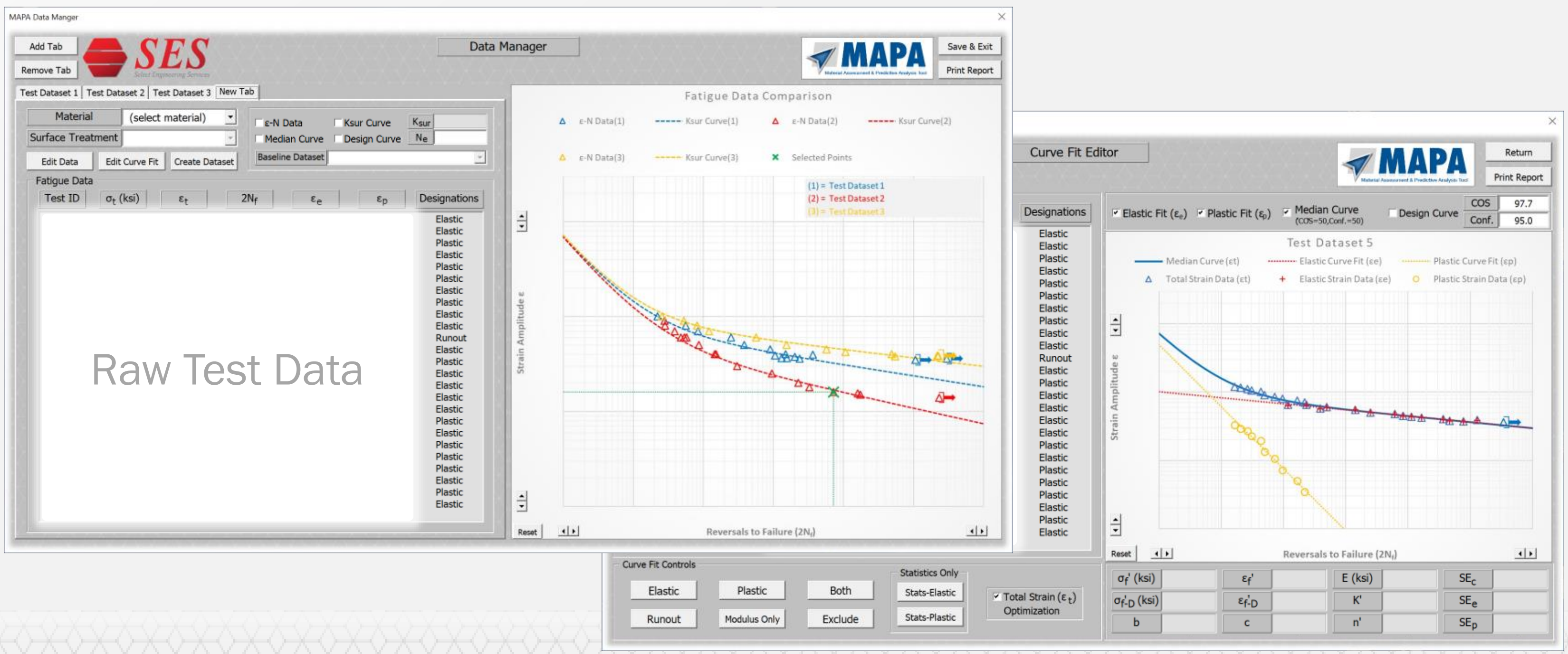
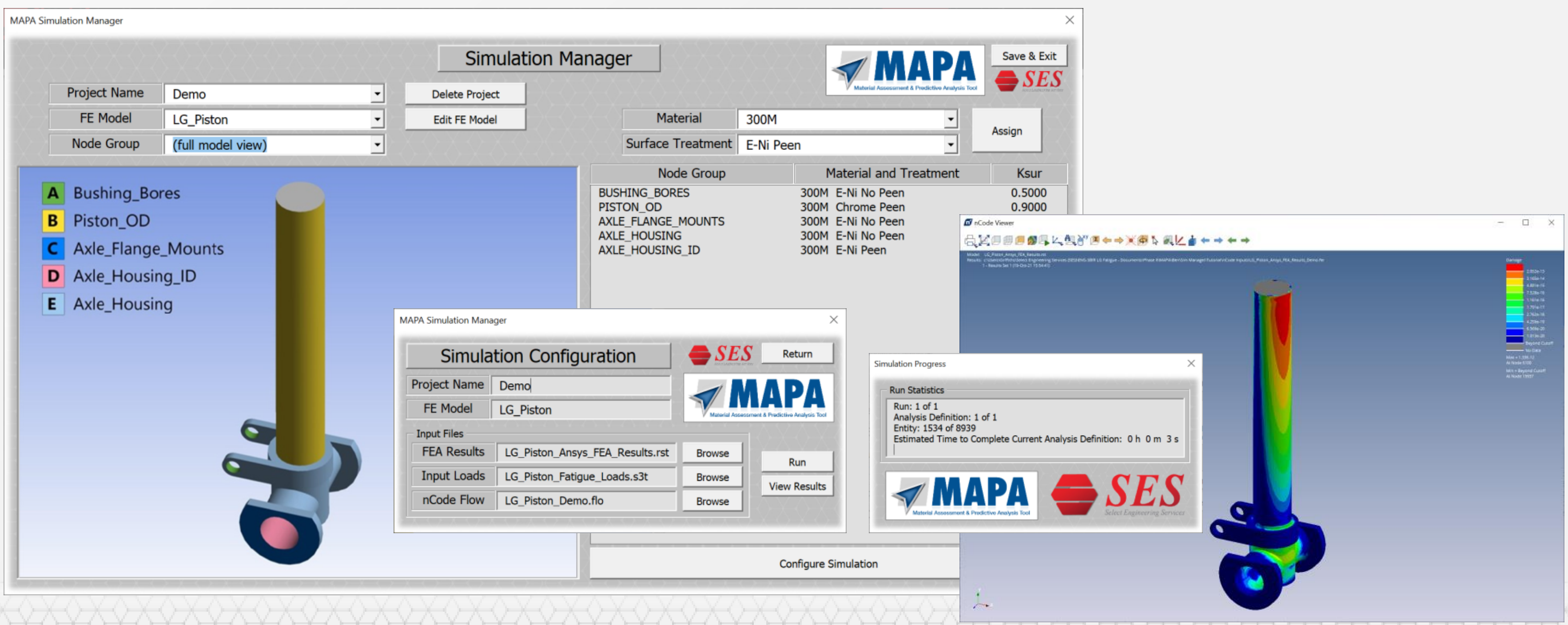
MAPA DATA MANAGER

- *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

- *Format node group files from ANSYS for input to nCode*
- *Automate material property assignment and bill of materials*
- *Preview model surfaces and associated material properties*
- *Efficiently save configuration/material assignments*
- *Execute nCode simulation in batch mode*



ONGOING EFFORTS

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- *Integrate* MAPA Material Assessment & Predictive Analysis Tool *with nCode* DesignLife
- *Expand surface treatment/material property database*
  - *Over 300 fatigue tests completed - 19 surface treatments, 3 materials*
- *Conduct residual stress and microstructure investigations*

https://www.airforcetimes.com/news/your-air-force/2019/02/01/c-5-conducts-nose-gear-up-emergency-landing-at-travis/

CLOSING

Questions/Comments

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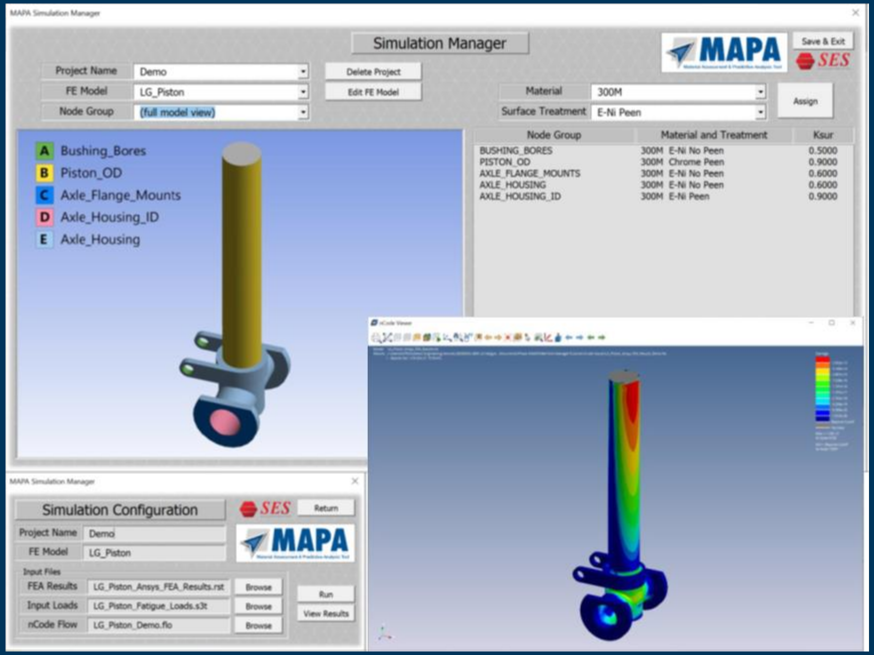

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