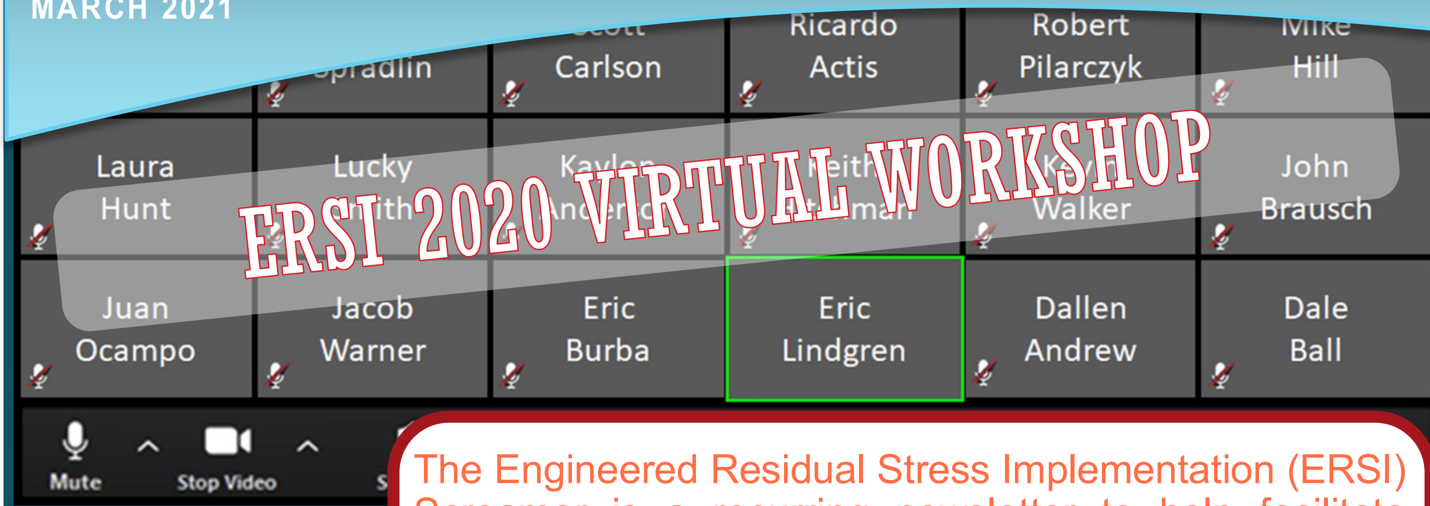
VOLUME 3
ISSUE 1

ERSI SCREAMER

MARCH 2021



This Issue

The Engineered Residual Stress Implementation (ERSI) Screamer is a recurring newsletter to help facilitate communication across ERSI committees and to all stakeholders in the aerospace community that have an interest in the implementation of residual stresses.

Purpose of ERSI

1) Develop a roadmap for the implementation of engineered deep residual stresses for calculation of initial and recurring inspection intervals for fatigue and fracture critical aerospace components.
2) Highlight gaps in state-of-the-art and define how they will be filled.
3) Define the most effective way to document requirements and guidelines for fleet-wide implementation.

Organization

The ERSI working group is broken up into 6 major committees with a chair for each, as shown below.

COMMITTEE NAME	CHAIR(S)
INTEGRATOR	Dr. Dale Ball (Lockheed Martin) Dr. TJ Spradlin (USAF AFRL)
FCG ANALYSIS METHODS & VALIDATION TESTING	Robert Pilarczyk (Hill Engineering) Jacob Warner (USAF A-10 ASIP)
RESIDUAL STRESS PROCESS SIMULATION	Keith Hitchman (FTI)
RESIDUAL STRESS MEASUREMENT	Dr. Mike Hill (Hill Engineering) Dr. Eric Burba (USAF AFRL)
NDI, NDE, DATA MANAGEMENT, & QUALITY ASSURANCE	John Brausch (USAF AFRL) Dr. Eric Lindgren (USAF AFRL) Kaylon Anderson (USAF A-10 ASIP)
RISK ANALYSIS & UNCERTAINTY QUANTIFICATION	Laura Hunt (SwRI) Dr. Juan Ocampo (St. Mary's Univ.)

ERSI Screamer Editors:

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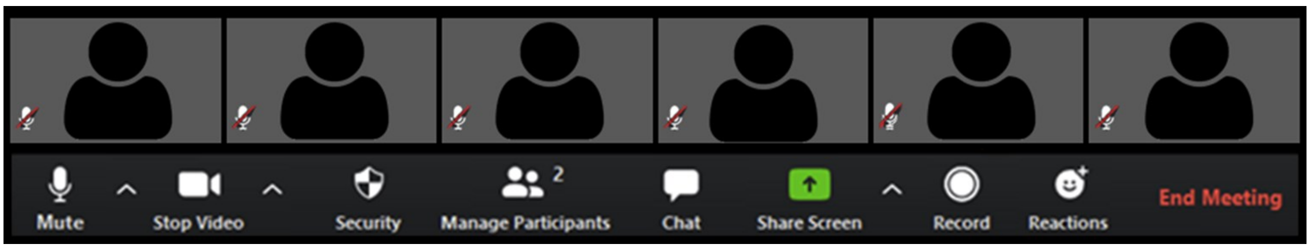
ERSI

ERSI as of December 2020

Countries Involved: **5**
DoD Organizations: **3 (+ FAA)**
USAF ASIP Managers: **10**
National Laboratory: **2**
Universities: **6**
OEMs: **3**
Industry Partners: **23**
ERSI Total: 155

5th Annual ERSI Workshop

The 2020 ERSI Workshop was held virtually on 8-10 December 2020 due to the COVID-19 pandemic. Virtual attendees included representatives of all three major airframe OEMs, both the USAF and USN, ASIP engineers from A-10, B-1, B-52, C-5, F-15, F-16, F-22, F-35, KC-135, and T-38, with much representation from industry partners and academia.

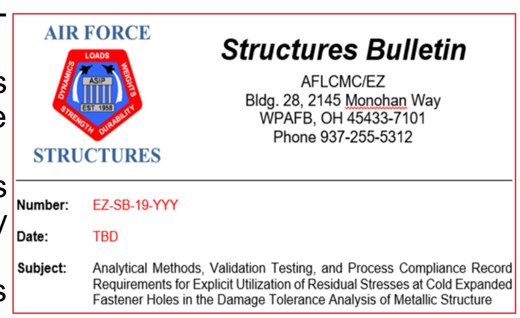


This issue of the Screamer provides an overview of the 2020 ERSI virtual workshop, which included virtual participants across the spectrum of ERSI members. The structure of the workshop was different than past years due to the online format, with the first day primarily focused on overview summaries of key activities accomplished within each committee over the past year. The second day was much shorter and strictly for the committee leads to have a focused discussion of ERSI objectives. The final day included a final summary of the committee leads discussion and an open town hall discussion for the entire working group.

The different sessions provided a well-rounded summary of ERSI related activities and highlighted the accomplishments over the past year, which included recent publications resulting from ERSI collaboration as well as the status of the draft USAF Structures Bulletin on the inclusion of engineered residual stresses in fatigue crack growth analysis methods. A high level summary of the open discussions from the workshop are also included.

Discussion Topic: USAF Structures Bulletin

- Feedback indicated lack of ERSI visibility of the status and scope of the bulletin needed to be addressed
- To enable collaboration with ERSI and get inputs from the working group, the last three versions of the bulletin were sent to the committee leads
- Leads will coordinate with their committee to address pertinent aspects of the bulletin and gather inputs by the end of March to facilitate updates by June
- Bulletin being routed through public release process to more broadly share with ERSI


AIR FORCE STRUCTURES

Structures Bulletin

AFLCMC/EZ
Bldg. 28, 2145 Monohan Way
WPAFB, OH 45433-7101
Phone 937-255-5312

Number: EZ-SB-19-YYY
Date: TBD
Subject: Analytical Methods, Validation Testing, and Process Compliance Record Requirements for Explicit Utilization of Residual Stresses at Cold Expanded Fastener Holes in the Damage Tolerance Analysis of Metallic Structure

5th Annual ERSI Workshop

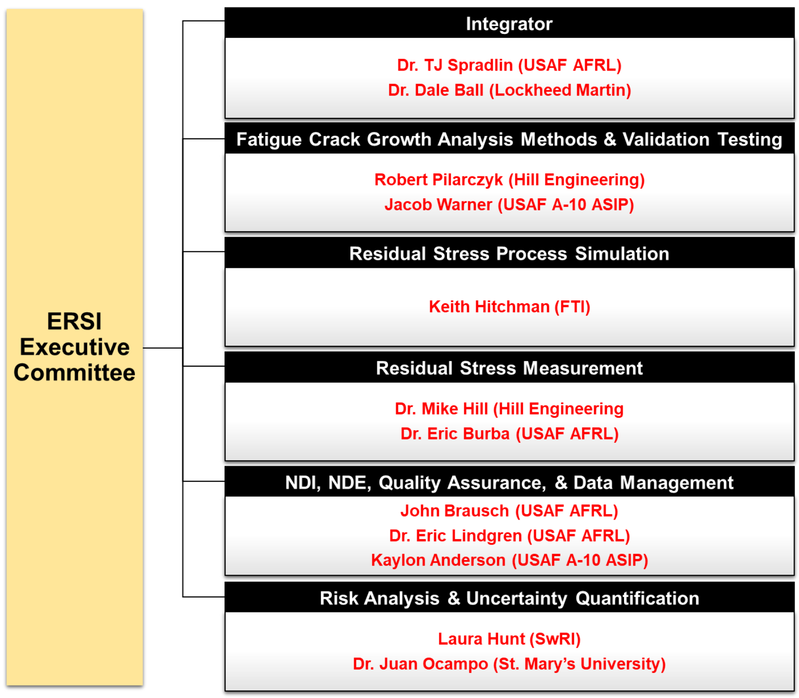
Discussion Topic: Communications Committee

The idea of standing up a communications committee was discussed that would coordinate the website, screamer, ASIP manager's collaboration, etc. A draft ERSI Communications Committee charge was put together for participants to review and provide recommendations:

- Responsible to help ERSI communicate effectively with internal & external stake holders
- Has one representative from each of the other ERSI standing committees
- Will have the following officers: Chair, Vice Chair, Webmaster, Screamer master
- Will facilitate and lead production of ERSI website and ERSI Screamer (quarterly)
- Will facilitate and lead planning of ERSI Workshop (annual) and ERSI ASIP Manger Update (twice a year, ASIP and AA&S)
- Will facilitate internal ERSI communications
- Will review and approve all outward facing communications and publications

Discussion Topic: ERSI Governance

It was discussed to develop a charter that would define organizational structure, purpose/goals, near and long-term objectives, and committee lead rotation. A reminder of the original vision, mission, and key objectives of ERSI are included below.



Vision: *Develop a framework for fleet-wide implementation of a more holistic, physics-based approach for taking analytical advantage of the deep residual stress field induced through the cold expansion process, into the calculations of initial and recurring inspection intervals for fatigue and fracture critical aerospace components.*

Mission Statement: *Develop a holistic paradigm for the implementation of engineered residual stresses into lifing of fatigue and fracture critical components*

ERSI Key Objectives

1) *Define a common vision for the accounting of engineered residual stress at cold expanded fastener holes*
2) *Provide forum to collaborate on new developments, best practices, & lessons learned*
3) *Develop an implementation roadmap*
4) *Identify, define, and enable the resolution of gaps in the state-of-the-art*

We welcome further expertise, participation, and input to the ERSI Working Group. Any individuals or entities interested in participating in ERSI please contact Dr. TJ Spradlin at thomas.spradlin.1@us.af.mil.

Fatigue Crack Growth Analysis Methods & Validation Testing (1/7)

Multi-Point MAI Program, NG-11: Verification, Validation, & Demonstration of Multi-Point Fracture Modeling Codes

NG-11 is a new program associated with the Metals Affordability Initiative and is being performed cooperatively with a team of government and industry participants

Air Force Research Laboratory

ATI ADVANCED TECHNOLOGY INTERNATIONAL

NORTHROP GRUMMAN

HILL ENGINEERING

Fracture Analysis Consultants, Inc

Objective

Validate and assess capability of three (3) multi-point fracture mechanics (MPFM) codes as applied to the linear elastic fracture mechanics (LEFM) analysis of Cx holes

- Broad Application for Multi-point Fatigue (BAMpF)
- Fracture Analysis Code 3D (FRANC3D)
- BEASY

Description	Analysis Configurations
Task 3.1 - Baseline Verification Specimens	
Analytical – Embedded Ellipse	2
Empirical – Compact Tension C(t)	1
Task 3.2 - Validation to level commensurate with traditional DTA methods	
Corner Crack at an Open Hole - Axial	4
Task 3.3 - Validation to level beyond traditional DTA methods	
Corner Crack at a Cold Worked Open Hole – Axial Load	8
Corner Crack at an Open Hole – Complex Load	2
Corner Crack at a Cold Worked Open Hole – Complex Load	2
Task 4 - Demonstration	
Fatigue Critical Location	1

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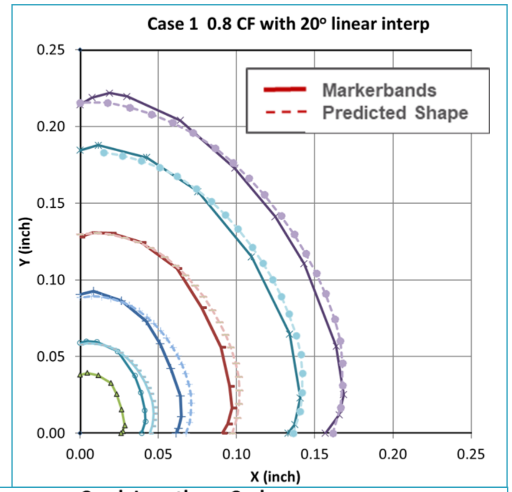
Fatigue Crack Growth Analysis Methods & Validation Testing (2/7)

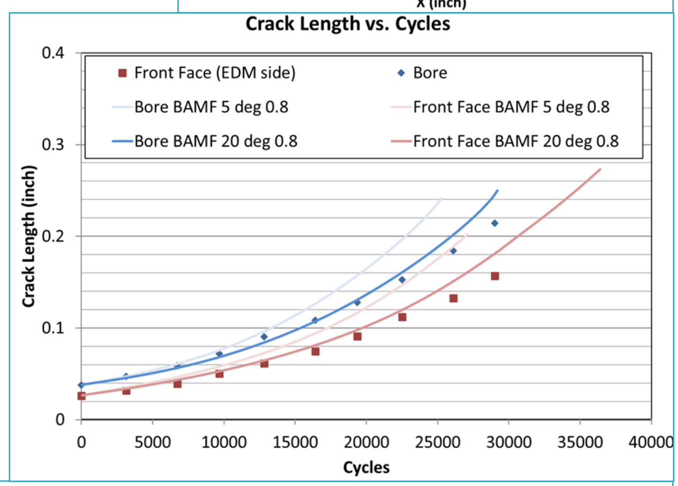
Surface Correction for Multi-Point Analysis



- AFGROW implementation of crack closure was investigated with impacts on A-10 control point analysis
  - Surface growth: Moderate life improvements (2-6%) and decrease in aspect ratio (2-5%)
  - Corner crack growth: Increased analytical predictions (2-37%) but little change in aspect ratio
- Methods utilizing multi-point analysis should consider investigating effects of closure factor
- Recommend performance of analytical study to compare multi-point growth with and without beta corrections at the free surfaces of the crack face

Approach

- Method developed to implement surface corrections into BAMpF using a max angle and a closure correction factor (CF)
- Initial predictions indicate a correction factor of 0.8 and a max angle of 20 degrees correlates best to test data
- Corrections appear to work for crack shapes in both CA and VA testing
- Corrections resulted in good life correction for CA tests, however, VA tests showed life that was longer than test



$$\beta_{surface\ correction} = \frac{(1-CF)}{Max_{angle}}\phi + CF$$

CF= Correction factor
Max Angle= Maximum angle the correction factor acts over
Φ=Angle from surface

Conclusion

- Initial experimentation to understand if we can consistently match observed test behavior
- How do we move forward from here to understand the physics of the behavior?
- What is the correct implementation approach?
- What data can we utilize to guide the approach?

Technical POC:
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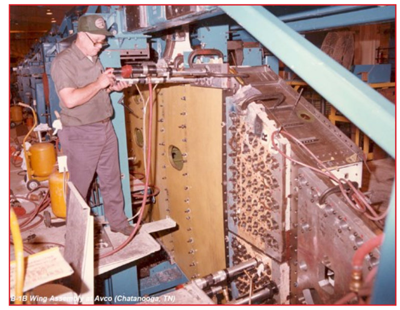
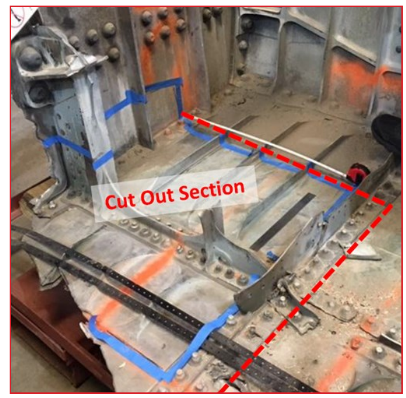
Fatigue Crack Growth Analysis Methods & Validation Testing (3/7)



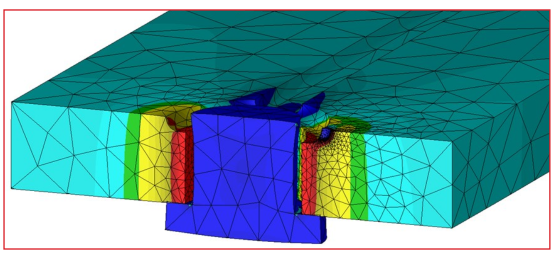


B-1 Taper-Lok Analysis & Testing

- Taper-Lok fasteners known to produce high levels of interference and residual stress
- Limited methods to quantify benefit of Taper-Lok installations
- B-1 Taper-Lok locations common to wing rear spar structure (Al material) and wing carry through structure (Ti material)

Objective

- Develop robust analytical approach to predict life at B-1 Taper-Lok fastener holes
- Perform measurements to quantify interference and residual stress at Taper-Lok holes
- Perform fatigue tests for representative Taper-Lok fastener hole conditions with representative coupon and excised component tests
- Perform FCG analyses for representative Taper-Lok conditions
- Perform damage tolerance assessments and assess inspection requirements for B-1 Taper-Lok fastener hole locations



Analytical Approach

- Investigate factors for explicit Taper-Lok modeling
- Hole propping/interference and residual stress
- Explicit modeling of fastener interference and residual stresses

Preliminary Results

- Combination of process simulations and residual stress measurements
    - Comparisons between model predictions and measurements look promising
- Validation testing for baseline and Taper-Lok conditions
    - Results look consistent
- Analysis vs. test comparisons
    - Wing process model prediction results show very well with test measurements, including baseline open hole and Taper-Lok configurations
- Extracted WCT structure test specimens
    - Completed residual interference, protrusion measurements, fastener & hole diameter measurements and residual stress characterizations
    - Fatigue test pending

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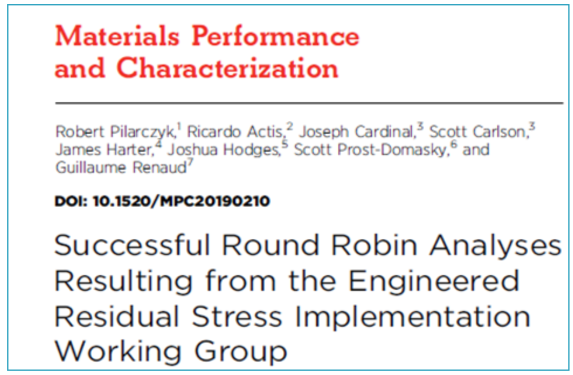
Fatigue Crack Growth Analysis Methods & Validation Testing (4/7)

Round Robin #1: Wrap-up

- Presented at 19th International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics (42nd National Symposium on Fatigue and Fracture Mechanics), May 2019
- Presented at the 2019 USAF ASIP Conference
- Published in Special Issue on Fatigue and Fracture Mechanics for Materials Performance and Characterization


Materials Performance and Characterization

Robert Pilarczyk,[1] Ricardo Actis,[2] Joseph Cardinal,[3] Scott Carlson,[3] James Harter,[4] Joshua Hodges,[5] Scott Prost-Domasky,[6] and Guillaume Renaud[7]

DOI: 10.1520/MPC20190210

Successful Round Robin Analyses Resulting from the Engineered Residual Stress Implementation Working Group

Round Robin #2: Interference Fit Fastener

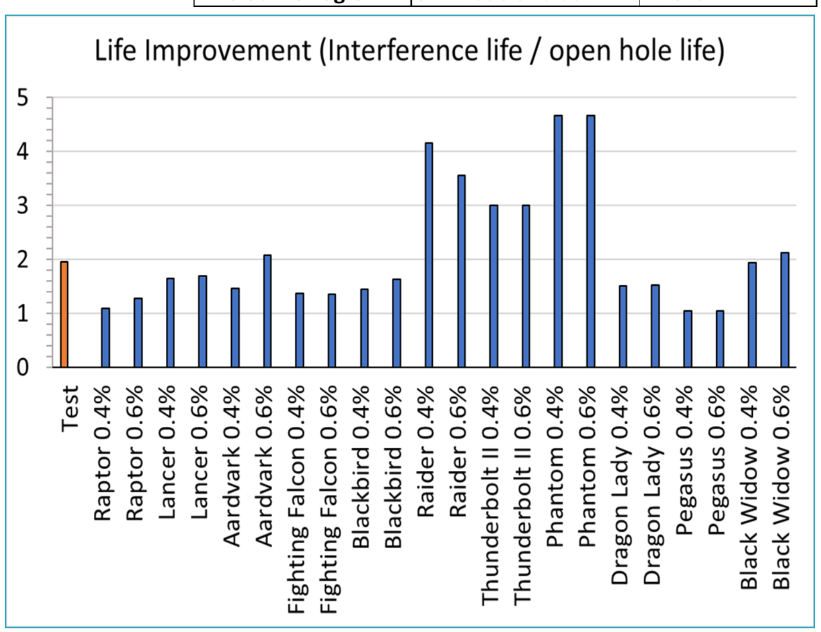
Interference fit fasteners are known to extend fatigue life, but that benefit is prohibited in design (JSSG-2006) and as a result not typically used in sustainment either.

	Crack Growth Engine	FEA Tool
P-61 Black Widow	AFGROW	MSC Marc 2019
U-2 Dragon Lady	AFGROW	StressCheck
KC-46 Pegasus	AFGROW	StressCheck
B-1 Lancer	AFGROW/ MS Excel	StressCheck
F-111 Aardvark	AFGROW	StressCheck
F-22 Raptor	AFGROW	StressCheck
SR-71 Blackbird	CPAT	StressCheck
F-16 Fighting Falcon	LifeWorks	StressCheck
A-10 Thunderbolt II	FASTRAN v 5.70	N/A
F-4 Phantom	FASTRAN v 5.70	N/A
B-21 Raider	FASTRAN v 5.42	N/A
B-2 Spirit	NASGRO	NASTRAN
F-15 Strike Eagle	SimModeler Crack	ANSYS

Objective

The goal of this effort is to assess the practicality of analytical models accounting for the benefit of interference fit fasteners in sustainment applications.

- 7075-T651 plate with Hi-Lok fastener
- Two (2) conditions tested
  - Open hole
  - 0.4% interference Hi-Lok
- Three (3) conditions predicted
  - Open hole
  - 0.4% interference
  - 0.6% interference
- 12 Participants, 13 Submissions



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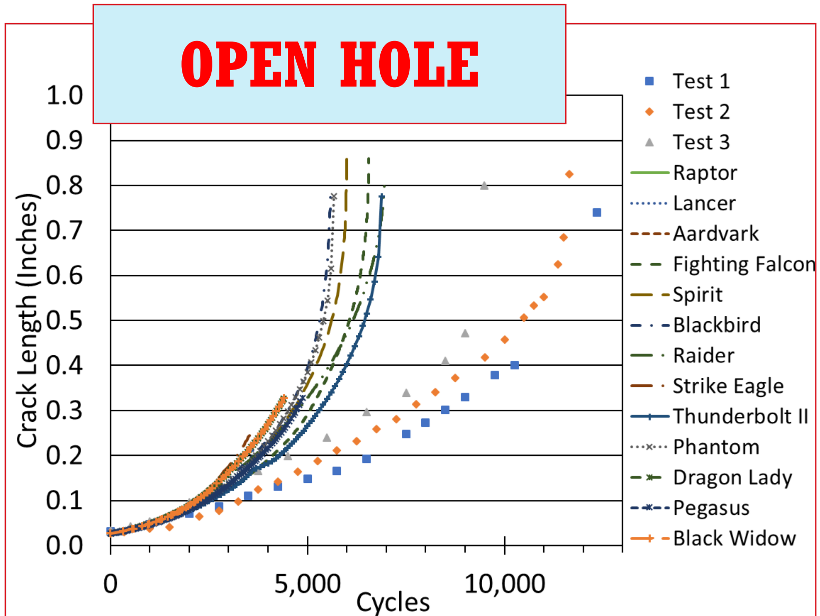
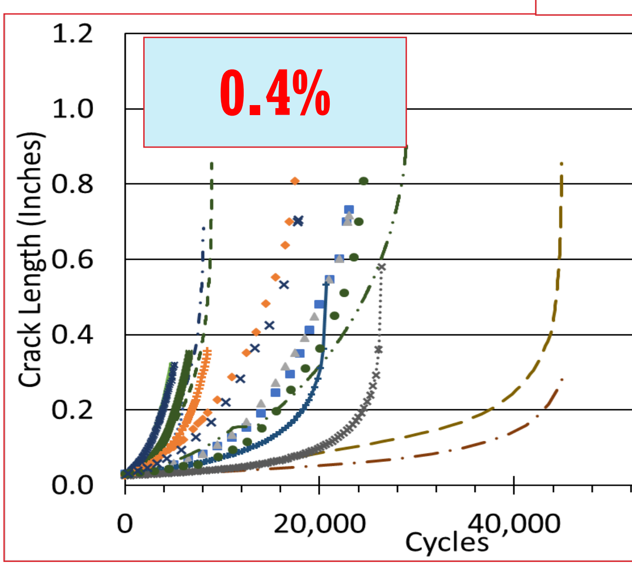
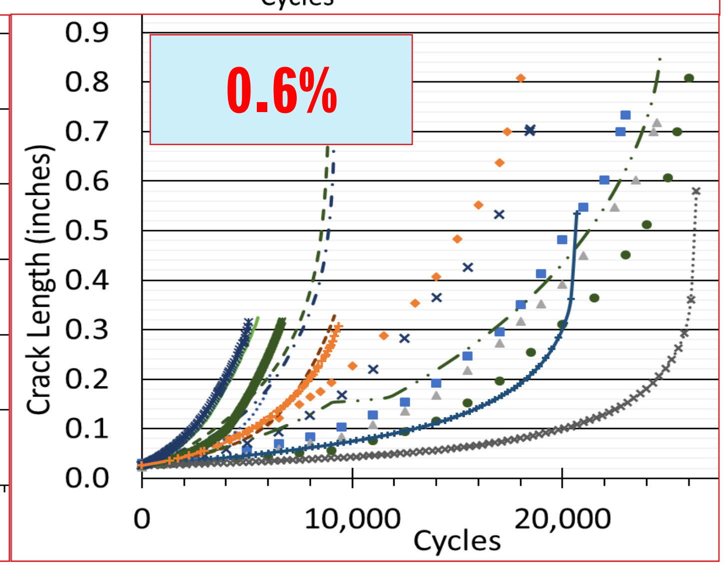
Fatigue Crack Growth Analysis Methods & Validation Testing (5/7)



<u>Test life improvement = 1.96</u>

- Average predicted life improvement = 2.15 (Outliers removed)
- Most prediction approaches resulted in conservative life improvement, which is encouraging for potential implementation.
- Majority of analytical approaches had limited sensitivity to % interference, also encouraging for implementation.
- Baseline open hole case had poor correlation with test which is being investigated. The discrepancy appears to be the result of a high applied stress.





<u>Conclusions:</u>

- Need to understand disparity between open hole predictions and test results
- Factor of two (2) life improvement despite high stress scenario
- Loading scenarios that avoid yielding should be evaluated
- Generally small difference between 0.4% and 0.6% predictions

<u>Technical POCs:</u>
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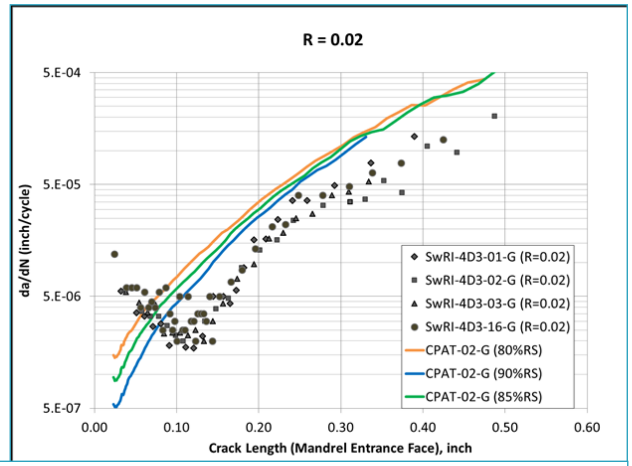
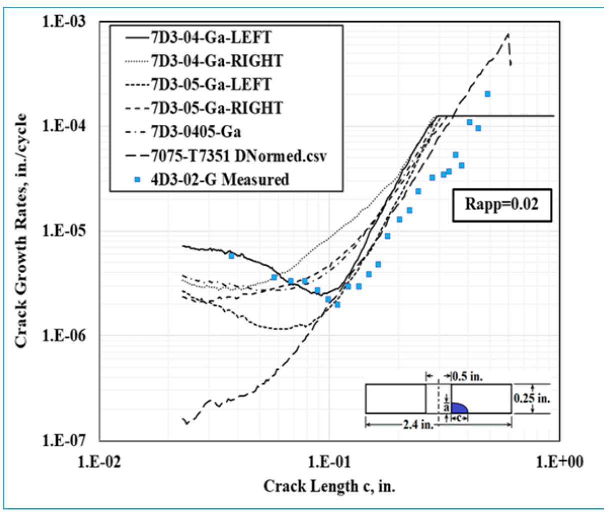
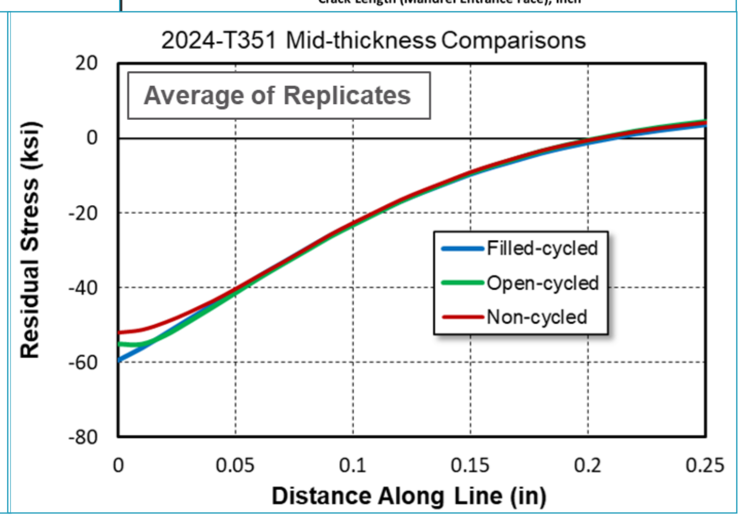
Fatigue Crack Growth Analysis Methods & Validation Testing (6/7)

Cyclic Redistribution

- Most fatigue crack growth testing at Cx holes has traditionally focused on lower stress ratios which show a characteristic dip in crack growth rates
- Crack propagation modeling efforts do not capture this behavior
- New program to investigate if differences in RS between non-cycled, open hole cycled, and filled hole cycled coupons could account for disagreement with test
    - Coupon configurations (18 total)
    - Material: 2024-T351 and 7075-T651







Summary

- Pre-cycled open and filled hole coupons did not result in appreciable changes in surface strains or residual stress relative to non-cycled coupons
- Residual stress changes were within 8ksi
- Redistribution of stress, as observed by APES in 7D3-04-Ga coupons, was not evident in measurement results
- Still reviewing data, however, additional investigation is necessary to understand details for 7D3-04-Ga coupons and any underlying keys to resulting residual stresses

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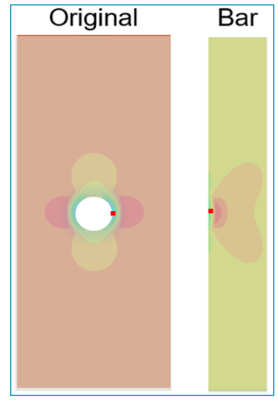
Dr. Tom Mills (APES), tmills@apesolutions.com

Fatigue Crack Growth Analysis Methods & Validation Testing (7/7)

Kt-Free Coupons

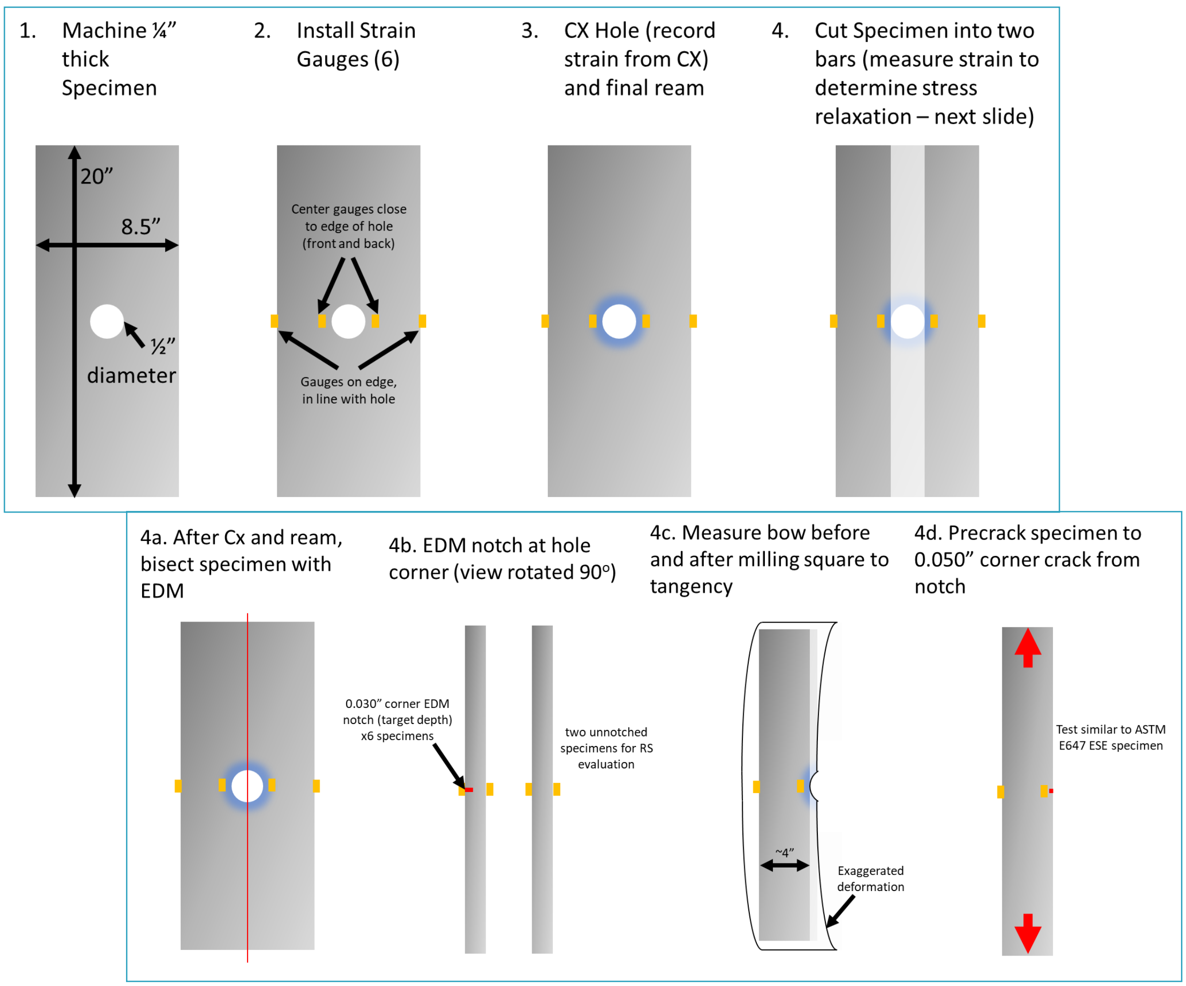
Objective: Eliminate effect of hole Kt while preserving some of Cx RS field to evaluate predicting growth through RS field without stress concentration

- FEA prediction indicates specimen with hole removed ("bar") has a RS field with same characteristic shape as specimen with the Cx hole
    - Will be verified with RS analysis
- FCG behavior will be compared to existing data for Cx hole coupons



Status

- Specimen preparation complete
- Testing of FCG specimens (x6) and RS specimens (x2) in work



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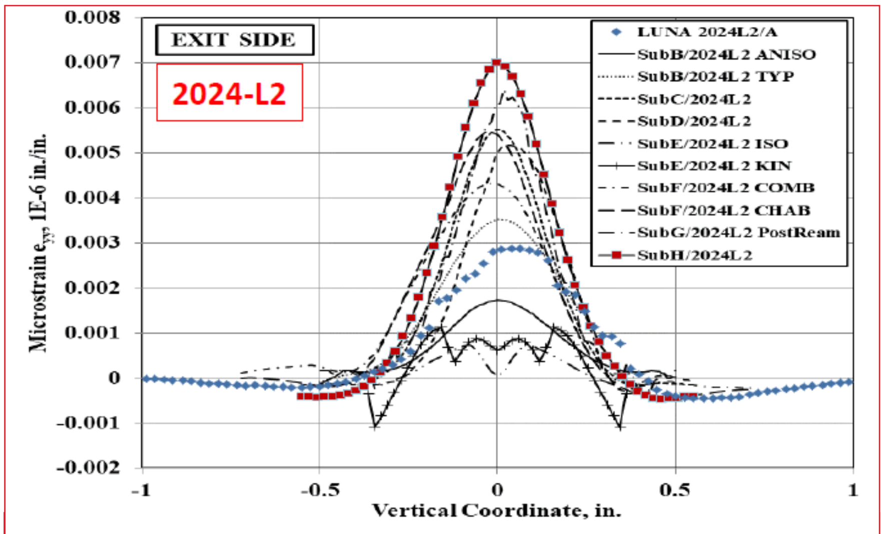
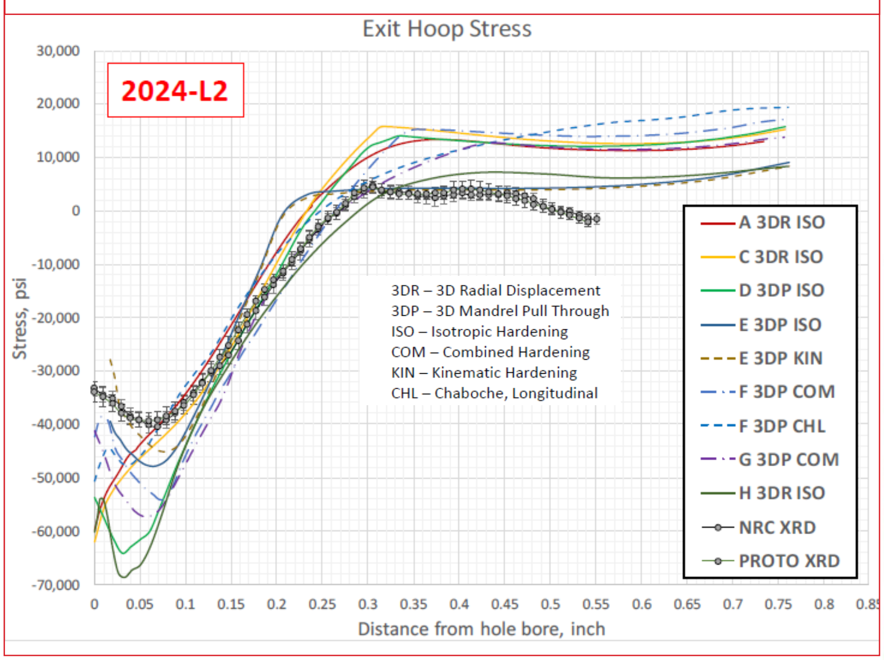
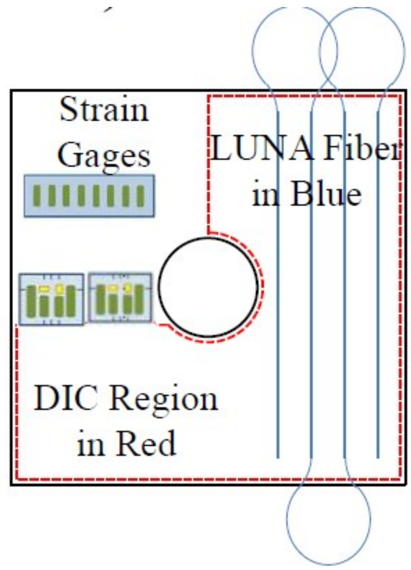
Residual Stress Process Simulation (1/2)

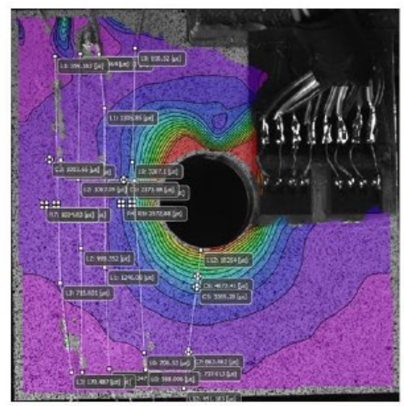
Residual Stress Process Simulation Round Robin

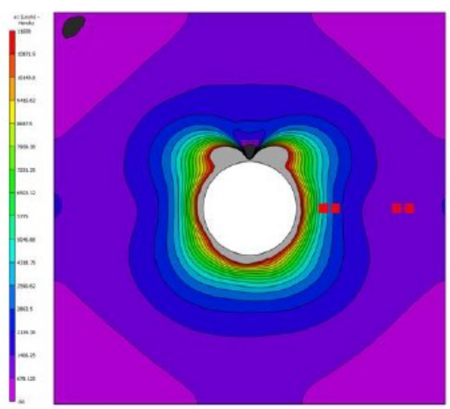
- Analysis of the 2”x2” Cx coupons
- Multiple measurement techniques offer a unique opportunity for process simulation validation and correlation
- Paper presenting round robin comparisons in work











FEA Hoop strains
Chaboche Hardening

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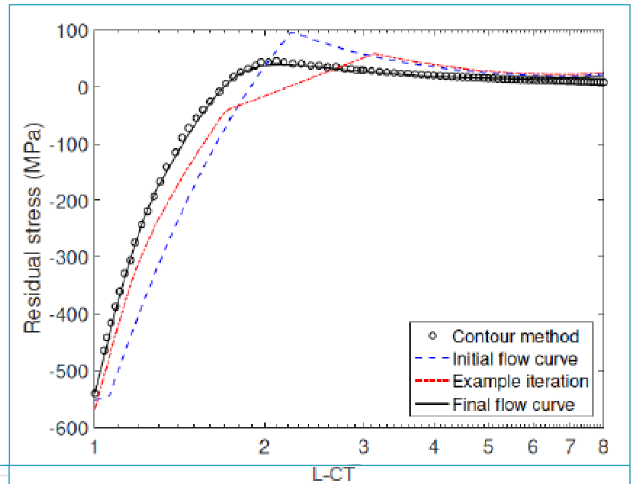
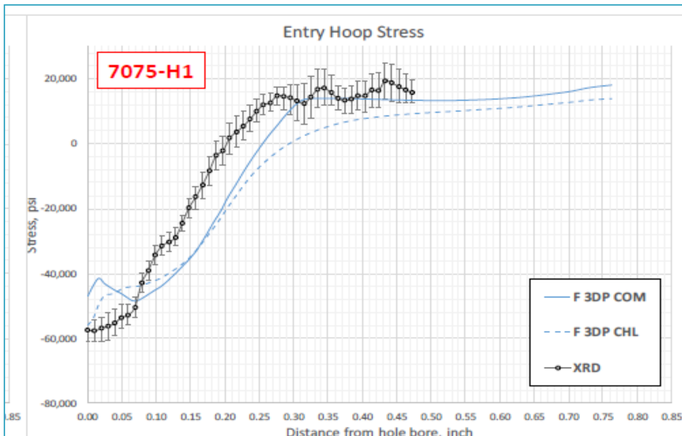
Residual Stress Process Simulation (2/2)

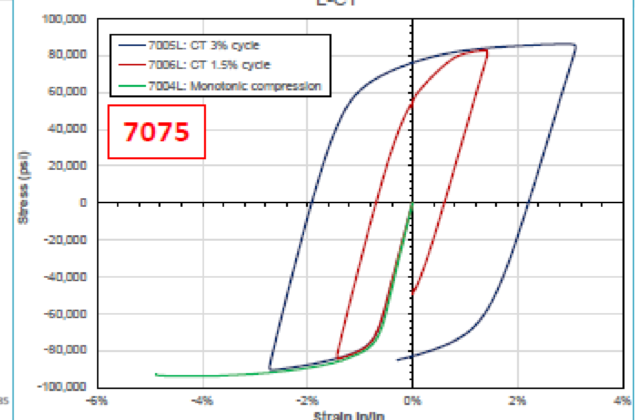
Material Model Testing

General plan based upon ASTM E606 Low Cycle Fatigue, up to ±4% in./in., reduced to ±1.5%

- Isolating current investigation to orthotropy
  - 2024 testing complete 2018
  - 7075 testing complete 2020
- Multiple submissions from seven participants
  - AP/ES, Hill Engineering, NRC Canada, University of Colorado Denver, Lockheed Martin, SwRI, FTI
- Multiple FEA software packages used
  - Abaqus, MARC, Nastran, StressCheck







Material Model Testing – New Results, 7075

Chaboche Parameter	NRC 3% L-TC		NRC 3% L-CT		NRC 3% LT-CT			Zehsaz, et. al.*
σ_{ys}, psi	49993		45720		42321			60000
C, psi	1.99e6	3.50e7	2.21e6	3.25e7	3.65e7	1.32e7	1.52e6	7.72e5
Υ	95.57	1795.80	113.79	1546.80	4845.10	782.45	90.37	31.06
Q, psi	1226		866		2574			19957
b	209.09		56.68		25.68			6.82
E, psi	9.992e6		1.149e7		1.128e7			1.06e7
ϵ	0.33		0.33		0.33			0.33

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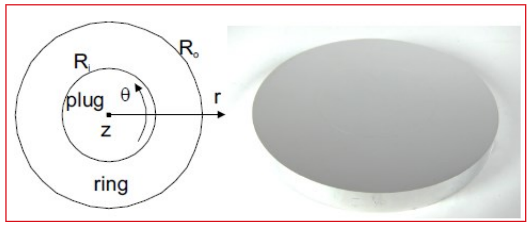
Dr. Guillaume Renaud (NRC Canada), guillaume.renaud@nrc-cnrc.gc.ca

Residual Stress Measurement (1/3)

Exemplar Data Sets: Near-Surface Stress Profiles

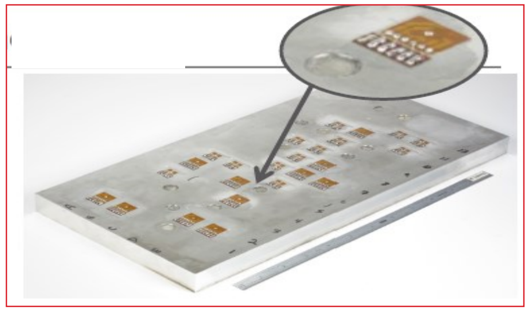
Objective

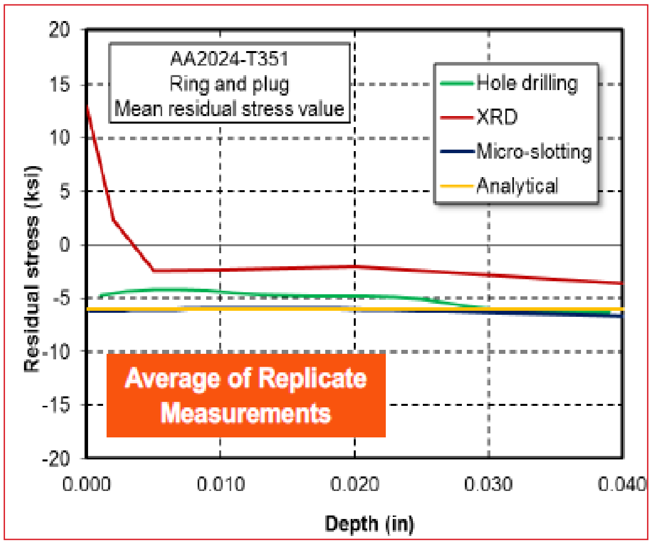
- Identify examples of residual stress measurement data that are typical of good practice in aerospace materials
- Seek data for comparisons of different experimental methods applied to same samples
- Measurement techniques: hole-drilling, XRD, and slotting



Inter-method comparison of near-surface stress profiling

- Sample type 1: Ring and plug
- Sample type 2: Plate specimens, 12 replicates
    - Shot peened AA7050-T7451
    - Shot peened Ti-6Al-4V (mill-annealed)
    - Quenched AA7050-T74





	Repeatability Std Dev (ksi) Average 0.00 to 0.04 inch		
Specimen	**XRD**	**HD**	**Slotting**
Aluminum ring and plug	2.2	1.1	0.4
Shot peened aluminum	2.5	3.0	1.1
Shot peened titanium	8.7	3.7	4.1
Quenched aluminum	2.0	1.4	1.0

Ring and plug results

- Near uniform compressive RS similar to expected value of -6 ksi
    - Slotting closely matches expected residual stress
    - Hole-drilling has similar shape, slightly different magnitude
    - XRD has different surface value and sub-surface bias (different value)
- Slotting repeatability better than 0.5 ksi (average); hole-drilling higher, and XRD largest
- Results show hole-drilling, XRD, slotting have similar results, differences in bias & precision

Technical POCs:
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Residual Stress Measurement (2/3)

2x2 Working Group Overview

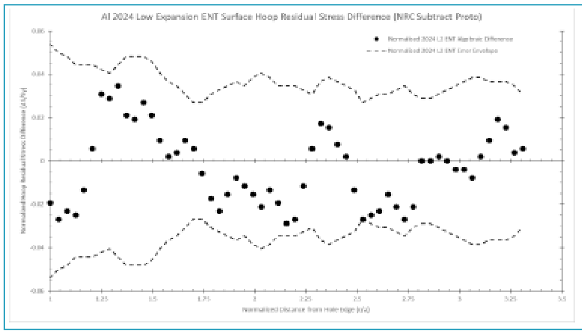
Purpose

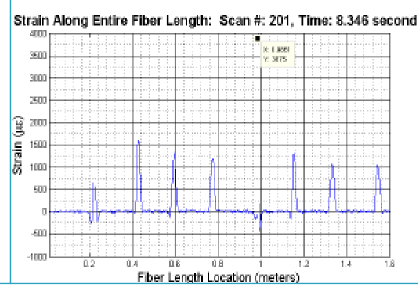
- Cx multiple aluminum alloys (2024-T351 & 7075-T651) at "Low" and "High" expansion levels for reamed and un-reamed configurations
- Characterize the residual stress/strain using multiple measurement techniques
    - Strain gauge, LUNA fiber optics, DIC, XRD, EDD, ND, Contour Method
- Develop a validation data set and framework for process simulations and NDI/QA
- Develop data for FCG validation

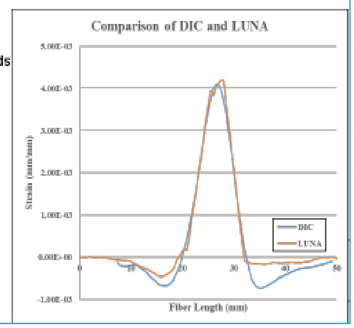
Surface Strain Highlights

- Multi-measurement cross validation
- DIC/FEM comparison
- Validation metrics established

Strain Comparison: Gauge vs. DIC			
Location	Gauge	DIC	%Diff
1	0.003571	0.003573	0.05%
2*	-0.005699	-0.005684	0.26%
3	0.000984	0.000969	1.54%
4	-0.000459	-0.000430	6.43%





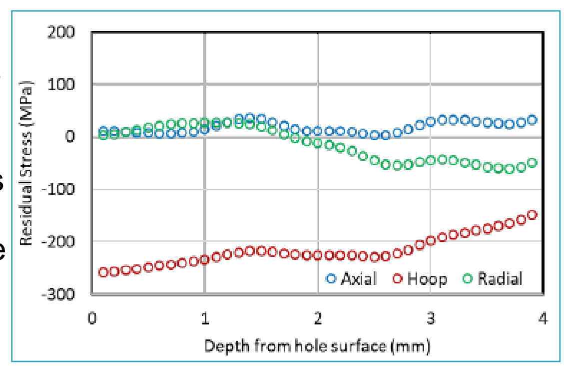


XRD Highlights

- Inter and Intra laboratory studies
- Optimize data collection parameters and take advantage of circumferential strain fields around Cx holes to further improve measurement accuracy & precision
- XEC determination for 2024-T351 & 7075-T651 product forms is currently in progress

ND Highlights

- Increased spatial resolution
- Requires thin foil for calibration & longer beam time



Work planned

- Additional ND and Contour Method measurements in Q1 & Q2 of 2021
- Residual stress data sets for FCG inputs should be established by Q4 2021
- Reamed coupons reserved for NDI, QA techniques
- Multiple journal papers in work

Technical POCs:
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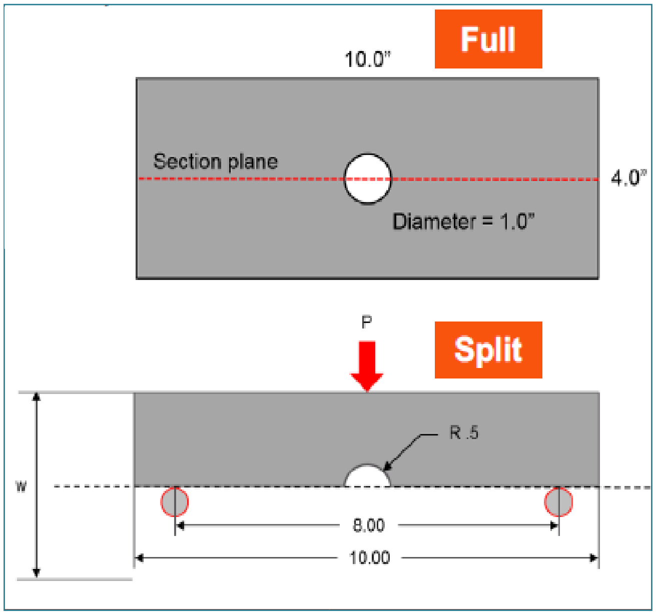
Residual Stress Measurement (3/3)

Large Hole Cx Evaluation

Objective

- Develop coupon that scales-up stress field
- Develop and interrogate residual stress measurement data
    - Full, Split configurations
- Develop FCG data in split configuration
- Materials: 7075-T651, 2024-T351



Status

- Coupon fabrication: Complete
- Residual stress measurements contour, hole drilling, XRD: Complete
- Comparison and assessment: in-process
- Fatigue crack growth testing of split samples: Straight bend complete
- Reporting: To be defined

Technical POCs:
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ERSI Texture & Anisotropy Team

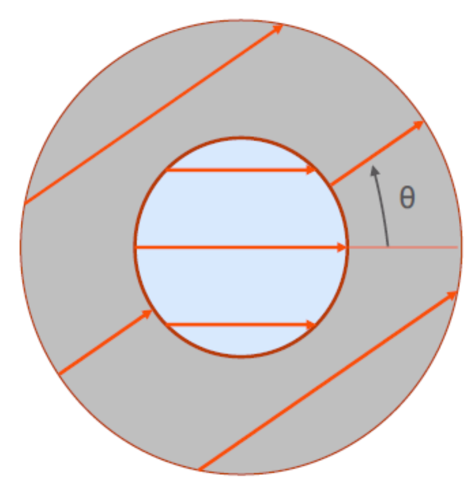
Objective

Incorporate elastic anisotropy into standard industry residual stress measurement workflows

Methods

Develop combined modeling and experimental approach to:

- Demonstrate impact of elastic anisotropy on current RS measurement techniques
- Incorporation of microstructure into existing workflows
- Support round robin sample sharing



Arrows indicate the dominate texture direction in each component
Model anisotropic material properties to determine theta with the greatest effect on plug/ring interaction

Schedule

- Dec 2020 – LANL prepares ring/plug samples
- Jan 2021 – AFRL begins hole drilling measurements
- FY21 – Anisotropic FE ring/plug model development
- FY21 – Measurement of 'optimized' plug samples

Technical POC:
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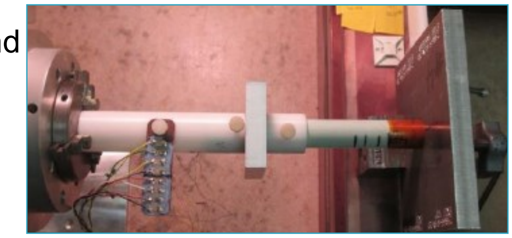
NDI, NDE, Quality Assurance, Data Management (1/3)

NDE to Detect and Quantify Residual Stress Fields in Cx Holes



Objective

- Verify ERS is present at Cx holes after service and quality assurance

Approach

- Includes multi-frequency, multi-probe approaches
  - Initial focus on eddy current methods
  - Ultrasonic techniques being evaluated
- Macro and micro effects in aluminum alloys first
- Integrates uncertainty quantification
- Year 1 of 4 year program complete

Structured Approach:

- Confounding factor assessment
- Rigorous test matrices
- Initial sample sets
- Will integrate structural variability

Preliminary Results:

- All methods sensitive to controlled residual stresses
- Changes measured are small –promising for QA
- Start to address hard problem: quantification

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Dr. Eric Lindgren (USAF AFRL), eric.lindgren@us.af.mil

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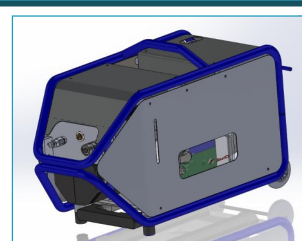
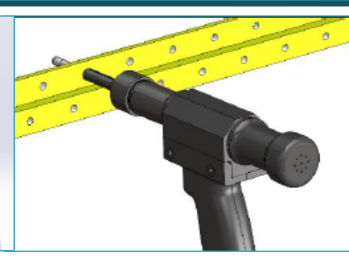
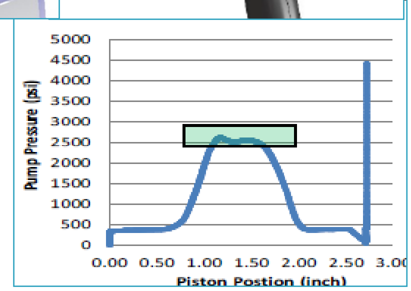




New hydraulic puller and powerpak integrating instrumentation & data analysis

- Fully electric operation
- Monitors load vs piston stroke data
- Process validation (Go/No Go)
- Process data log for archive records
- Compatible with legacy FTI processes & Data Spatial Position systems



Technical POC:

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NDI, NDE, Quality Assurance, Data Management (2/3)

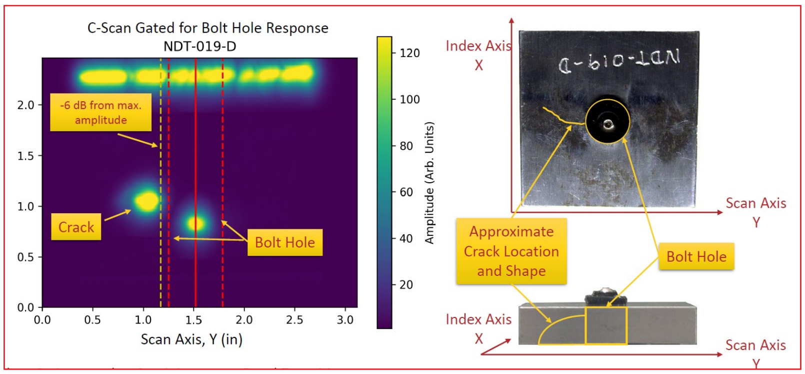
UT Dead Zone Characterization in Cx Holes

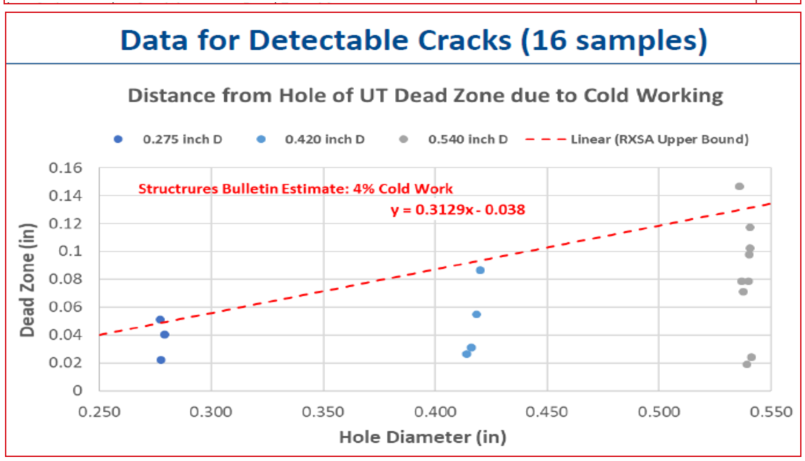
Round Robin Testing

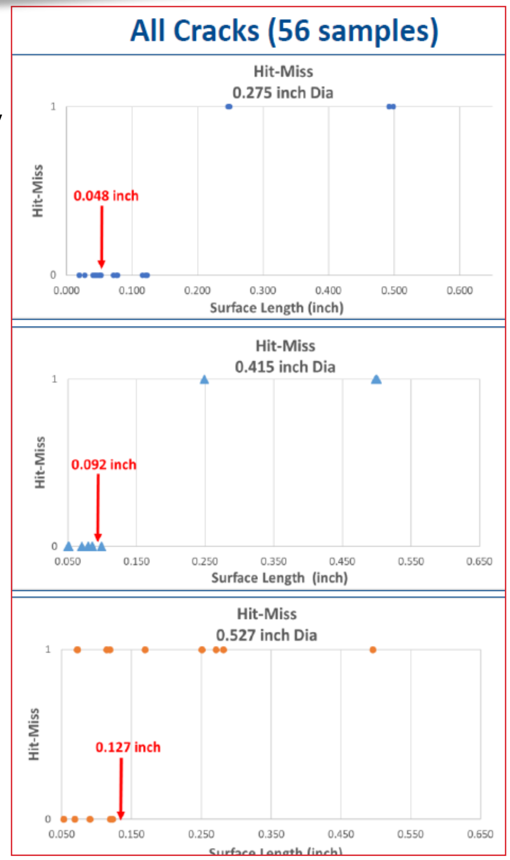
- Characterize effect of residual stresses on detectability of fatigue cracks with ultrasound
- 117 Specimens, 4% Cx, 7075-T6
- 3 hole diameters (0.278", 0.418", 0.538")
- 3 plate thicknesses (0.1", 0.313", 0.5")
- Fatigue cracks: 0.020 inch thru-thickness

Procedure for Dead Zone Measurement

- C-Scan Gated for Bolt Hole Response







Results

- 117 samples examined (56 with verified fatigue cracks)
- Measurable ultrasonic dead zone in 16 samples, cracks not detectable with ultrasonics in remaining samples
- Trend of dead zone size proportional to hole diameter
- RXCA measured dead zones trend slightly smaller compared to RXSA measurements

Comparison to Current Assumptions

- Considerable variability in results
- Missed cracks greater than prediction are concerning
- Further analysis of 0.275 in diameter hole samples initiated
- Next: Correlate dead zone estimates to residual stress profiles –collaboration required

Technical POC:
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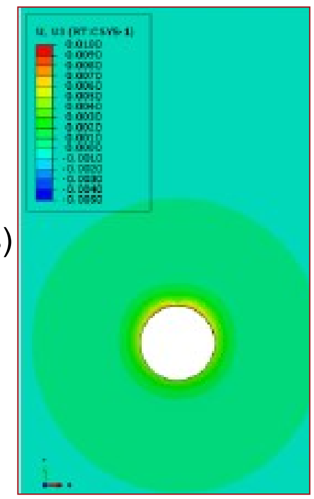
NDI, NDE, Quality Assurance, Data Management (3/3)

FastenerCam™ for QA/QC of Cx Fastener Holes

- Handheld laser profilometer and software package
- Measures Cx at fastener holes (quality assurance)
- Provides options for:
  - Good/Bad (Green light/red light)
  - Full data capture (entire set of profile data)
- Interfaces with NLign for reporting

Current status
- Ruggedized manufacturing prototype developed
  - 8 hr battery, 2 TB HD, touch screen tablet
- Use cases include:
  - 2024 and 7075 Al alloys
  - Straight holes, multi layers, off-angle pulls



Next steps
- Develop/Implement profilometry capabilities (scanning and analysis) for csk Cx holes
- Manufacture an upgraded version for straight and countersunk holes
- Repeatability and reliability study to integrate into tech orders

Technical POCs:
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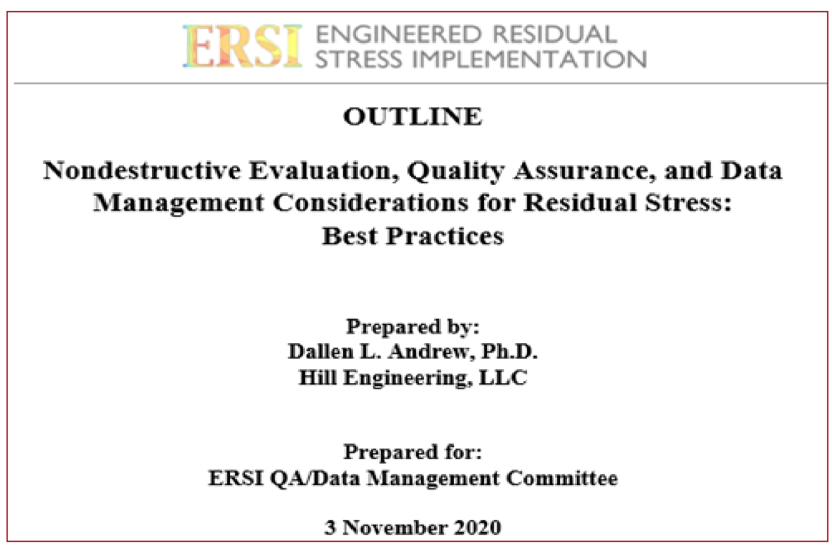
Kaylon Anderson (USAF A-10 ASIP), kaylon.anderson@us.af.mil

Best Practices Document

- Significant progress made to NDI/NDE/QA/Data Management Best Practices document
- Feedback has been gathered from ERSI committee members and revisions are in-work



ERSI ENGINEERED RESIDUAL STRESS IMPLEMENTATION

OUTLINE

Nondestructive Evaluation, Quality Assurance, and Data Management Considerations for Residual Stress: Best Practices

Prepared by:
Dallen L. Andrew, Ph.D.
Hill Engineering, LLC

Prepared for:
ERSI QA/Data Management Committee

3 November 2020

Technical POCs:
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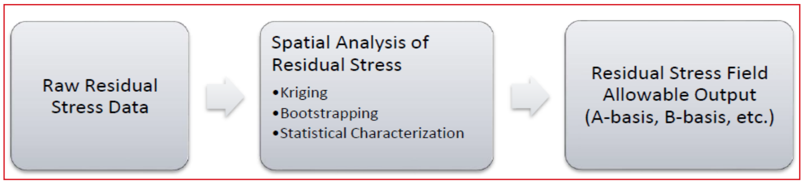
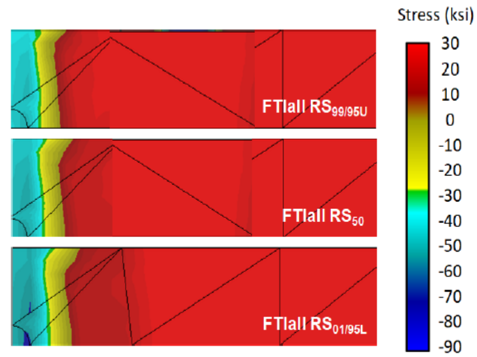
Risk Analysis & Uncertainty Quantification (1/2)

Residual Stress Characterization for Cx Utilizing Spatial Statistics: The Spatial Analysis of Residual Stress (SpARS) Methodology

Purpose

- Develop process to statistically quantify RS fields from Cx by utilizing spatial statistical methods, & quantify impact on analytical fatigue crack growth life

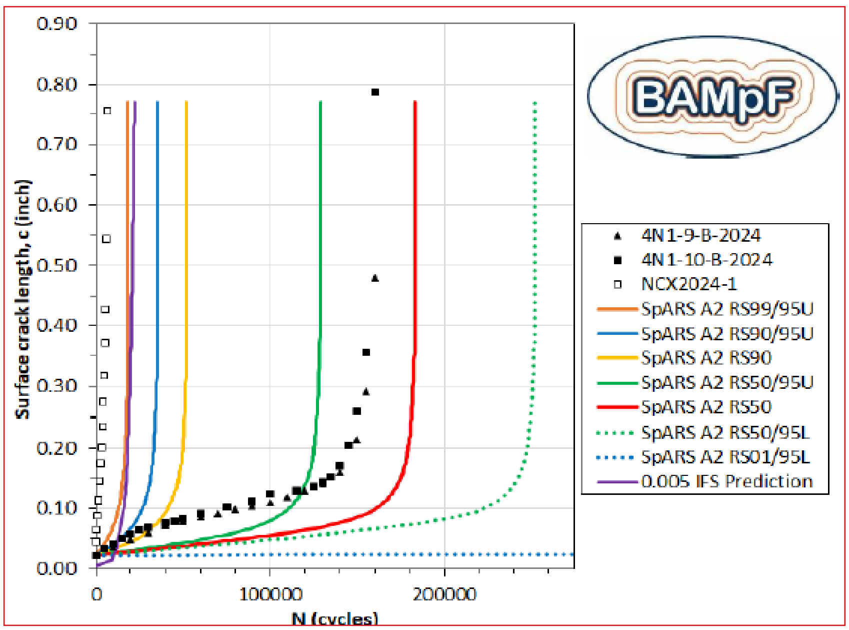


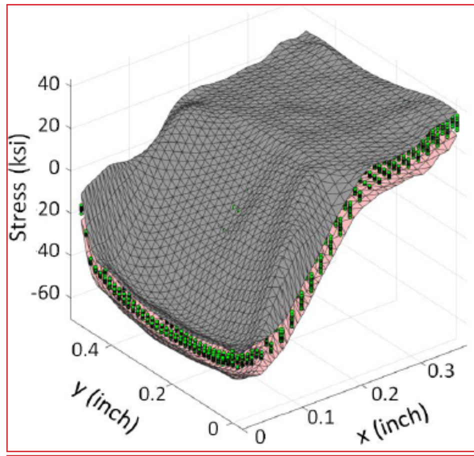


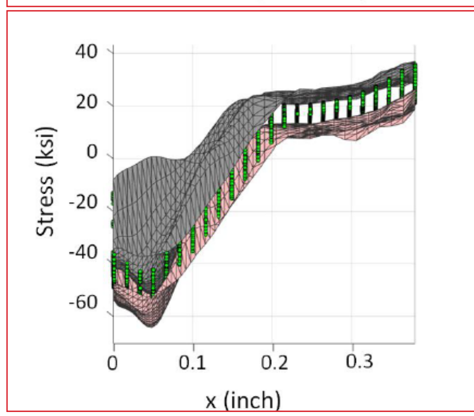
Andrew et al. Characterization of residual stresses from cold expansion using spatial statistics. Fatigue Fract Eng Mater Struct. 2020; 1– 14.

Results

- RS tolerance bound surfaces
- FCG analyses using BAMpF
  - 2024-T351, D=0.5", t=0.25", min %Cx
  - Benefit from SpARS allowable RS fields compared to 0.005" approach
- Selected upper bound was $RS_{50/95U}$







- Conclusion:
- SpARS addresses one leg of stool and is an acceptable means of compliance for the draft structures bulletin

Technical POC:
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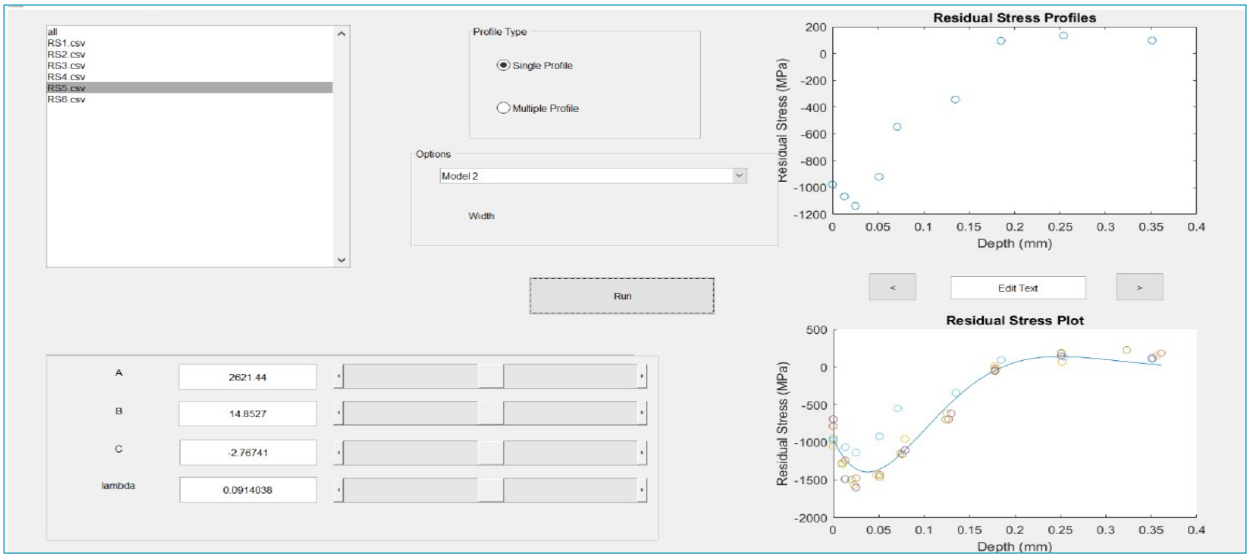
Risk Analysis & Uncertainty Quantification (2/2)

Residual Stresses Activities at St. Mary's University

Residual Stress Modeling Software

- Standalone executable to read RS data, find best deterministic/probabilistic fit parameters
- 2 models available (expandable)
- 2D (stress vs depth) and 3D (stress vs depth vs thickness)



Technical POC:
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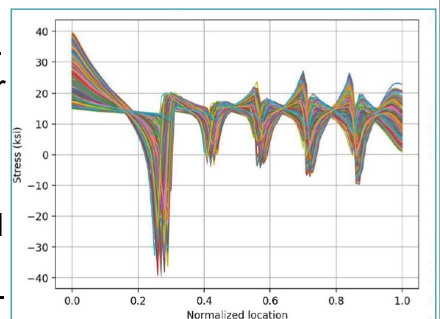
Stress Gradient Surrogate Model Using Principal Components Analysis

Objective

- Create a fast-running surrogate model that is capable of predicting stress gradient (in given direction and at particular location) as a function of a set of selected variables



- 250 axial stress gradients in a pressure vessel weld based on 7-variable DOE
- 101 points along each gradient

Approach

- Use Latin Hypercube DOE to generate surrogate model training data over range of values for input variables
- Use PCA to express stress gradient using reduced set of co-ordinates
- Fit Gaussian Process (GP) regression models to predict PC scores, which can be used to reconstruct full stress gradients
- PCA represents the variations in the high-dimensional stress field (101 locations) using a smaller number of coordinates (the principal components)
- Response surfaces will relate input variables to principal components (sensitivity analysis)
- Equilibrium is naturally enforced to a degree, an optimization formulation will improve it

Technical POC:
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Announcements

- **Upcoming ERSI related events:**
    - ASTM E08 Committee Week, May 17-19, 2021, Virtual
    - AA&S Conference, Aug.16-19, 2021 in Bonita Springs, FL and Virtual
    - ASTM E08 Committee Week, Nov. 15-18, 2021 in Atlanta, GA
    - ASIP Conference, Nov. 29-Dec. 2, 2021 in Austin TX and Virtual

- **ERSI committee participation**
    - We encourage you to continue to discuss ERSI-related topics with colleagues, at conferences, and in other technical interchanges. If you find there are others who would like to participate, please refer them to the applicable committee chair(s).

- **ERSI website**
    - If you have an account, go to https://member-ersi.swri.org and login. If you need an account, please send an email to Lucky Smith at luciano.smith@swri.org and an account will be created for you. Please include your name, organization, and contact information.