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ERSI SCREAMER

this issue

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The Who, What, and Why of ERSI

For those who are new to the Engineered Residual Stress Implementation (ERSI) working group, the ERSI Screamer is a recurring newsletter designed to facilitate communication within and outside the ERSI working group. A brief description of the who, what, and why of ERSI is included here. We've recently reviewed and updated our Mission Statement and Key Objectives to align with the evolution of ERSI since its inception.

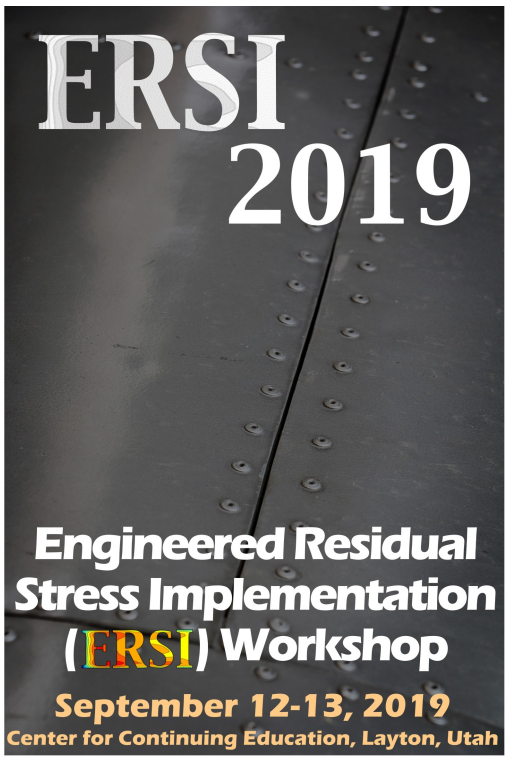
Sponsoring Organization: This working group is sponsored by the United States Air Force (USAF) Aircraft Structural Integrity Program (ASIP) under the direction and guidance of Mr. Chuck Babish.

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

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

Organization: The Working Group is broken up into 8 committees with a chair for each, as shown below. If anyone is interested in being a committee chair, please contact one of the ERSI Organizers.

Committee	Chair(s)
INTEGRATOR	Dr. Dale Ball (Lockheed Martin) & Dr. TJ Spradlin (USAF AFRL)
VALIDATION TESTING	Mr. Jacob Warner (USAF A-10 ASIP)
RESIDUAL STRESS PROCESS SIMULATION	Mr. Keith Hitchman (FTI)
FCG ANALYSIS METHODS	Mr. Robert Pilarczyk (Hill Engineering)
DATA MANAGEMENT/QUALITY ASSURANCE	Mr. Kaylon Anderson (USAF A-10 ASIP)
NON-DESTRUCTIVE INSPECTION	Mr. John Brausch (USAF AFRL)
RISK ANALYSIS & UNCERTAINTY QUANTIFICATION	Ms. Laura Hunt (SwRI) & Mr. Lucky Smith (SwRI)
RESIDUAL STRESS MEASUREMENT	Dr. Mike Hill (Hill Engineering)



4th Annual ERSI Workshop

The 2019 ERSI Workshop was held at the Layton Weber State University campus on September 12-13, 2019. Attending were representatives of all three major airframe OEMs, both the USAF and USN, and ASIP engineers from A-10, B-1, B-52, C-5, F-16, F-15, F-22, KC-135, and T-38. In addition we had representation from our industry partners and academia.

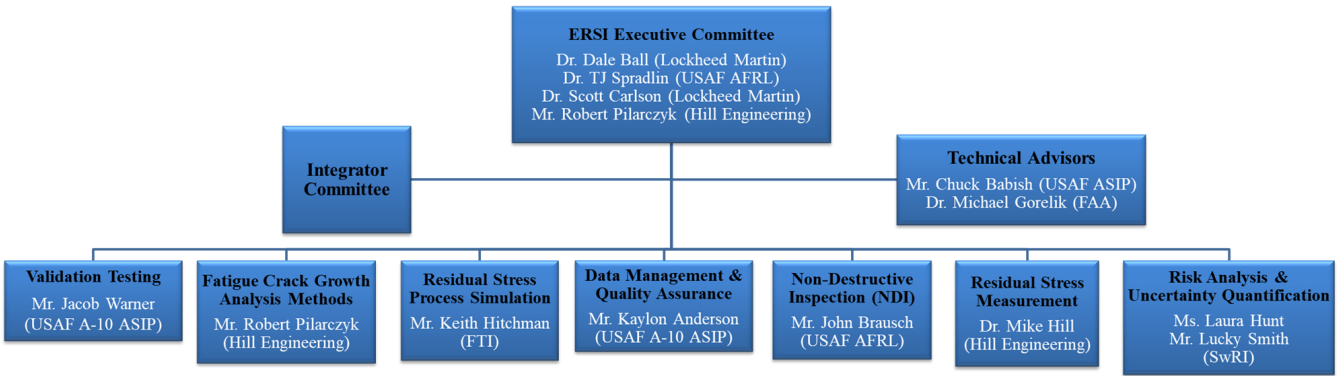
This year's workshop was quite successful with participants across the spectrum of ERSI members. The structure of the workshop was similar to last year with the first day primarily focused on overview summaries of key activities accomplished within each committee over the past year. These overview summaries were followed by committee breakout sessions which focused on a detailed review of accomplishments from the last year. Also, at the end of the second day a specific government only session was hosted by TJ Spradlin to discuss collaboration across the various USAF ASIP offices.

Key discussion points of the workshop included round robin efforts, residual stress redistribution, short edge margin and geometrically large testing, weapon system specific applications, ultrasonic dead zone characterization, Taper-Lok applications, material model testing, residual stress measurement goals, and a review of recent initiatives to develop validated QA/NDE methods. The overviews provided a well-rounded summary of ERSI related activities and highlighted the accomplishments over the past year. Also, recent publications resulting from ERSI collaboration was discussed as well as the status of the upcoming USAF Structures Bulletin focusing on the inclusion of engineered residual stresses in fatigue crack growth analysis methods.

ERSI Involvement as of June 2019

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

During the breakout sessions, each committee discussed remaining gaps and defined key initiatives moving forward. These initiatives will guide the focus areas for the upcoming year and establish the discussion points for next year's workshop. The organizational structure of ERSI is shown below.



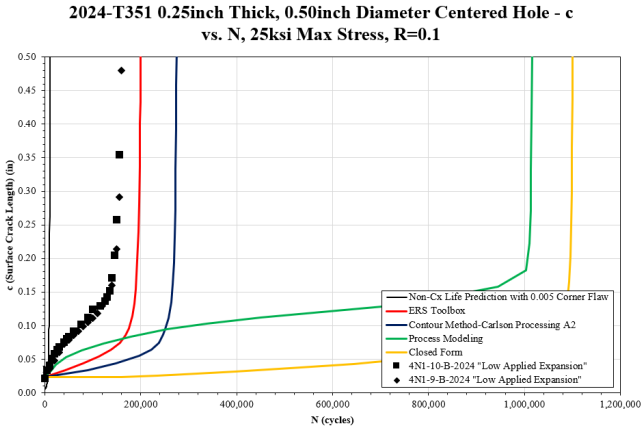
Committee Spot

Fatigue Crack Growth Analysis

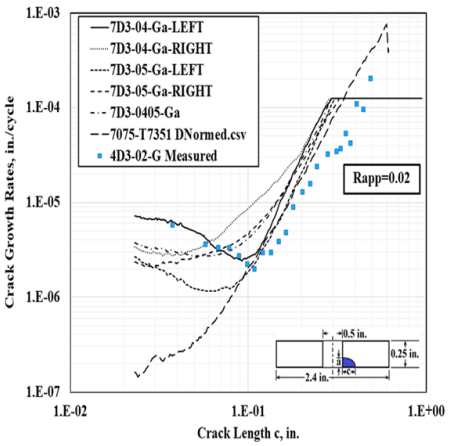
The fatigue crack growth analysis methods committee presented a wide range of ERSI related initiatives accomplished over the past year. These initiatives focused on round robin efforts, specific modeling efforts, weapon system specific applications, and misc. other items. Some of the modeling efforts focused on residual stress source comparisons, material characterization, closure modeling, residual stress redistribution, notch plasticity impacts, testing of complex coupons with quenched residual stress, and fatigue life variability as a function of input variance. The committee also discussed initiatives to support the development of a new USAF Structures Bulletin as well as a collaboratively developed literature summary. Several of the key discussion points of the committee are detailed below.

Round Robin Efforts: The round robin initiatives have proven to be quite productive for the ERSI working group. The initial round robin focused on the epistemic uncertainties in the prediction of fatigue crack growth at cold expanded fastener holes, given a fixed set of input data. The results of this initial round robin was recently presented at the 19th International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics and will be published in the upcoming special issue on Fatigue and Fracture Mechanics for Materials Performance and Characterization. A follow-on round robin was discussed at the workshop and will focus on fatigue predictions for interference fastener applications. An initial summary of the round robin details was presented to the committee in November and final details are being completed. Please let us know if you'd like to participate.

Residual Stress Source Comparisons: As a follow-on to the initial round robin, residual stress source comparisons were completed investigating the various methods available to characterize the residual stress at a cold expanded fastener hole. These sources included destructive measurements (contour), elastic-plastic process simulation, closed-form solutions, and an Eigenstrain approach. Utilizing the residual stress sources, two separate crack growth engines (BAMF and CGRO) were utilized for predictions. Predicted and experimental results were compared. Follow-on efforts will focus on "short'" edge margin conditions.



Residual Stress Redistribution: Correlations between predicted and experimental crack growth curve shapes have been a challenge at Cx holes. This disparity has resulted in a focused effort to understand the underlying issues in the analytical predictions. Past studies have primarily focused on crack closure mechanisms, however, recent investigations have uncovered a possible culprit. Recent residual stress measurements have indicated an initial redistribution of residual stress as a result of pre-cycling. Utilizing residual stress measurements from pre-cycled coupons, APES was able to successfully match crack growth lives and curve shape without any adjustments to the as-measured residual stresses. These results are quite promising and follow-on tests are underway to see if the results can be repeated for similar conditions as well as a different aluminum alloy. The results of this follow-on effort will be presented at the 2020 ERSI Workshop.



POC: Mr. Robert Pilarczyk (Hill Engineering, LLC); rtpilarczyk@hill-engineering.com

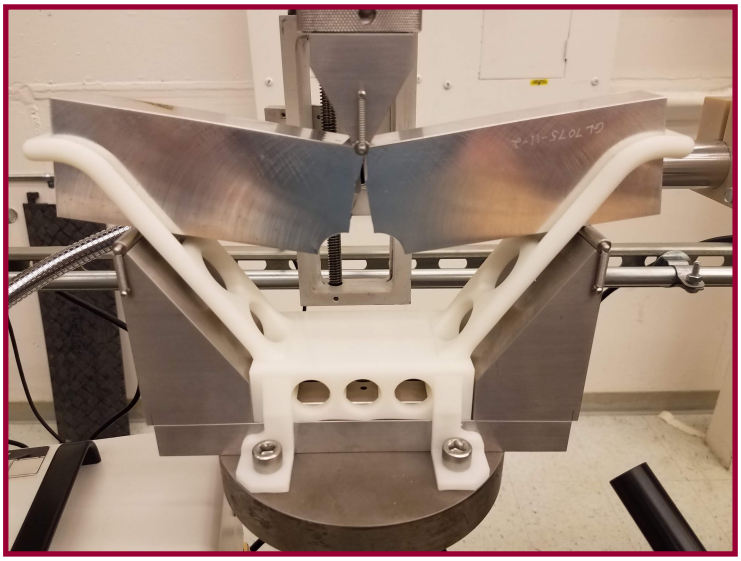
Validation Testing

Committee Spotlight

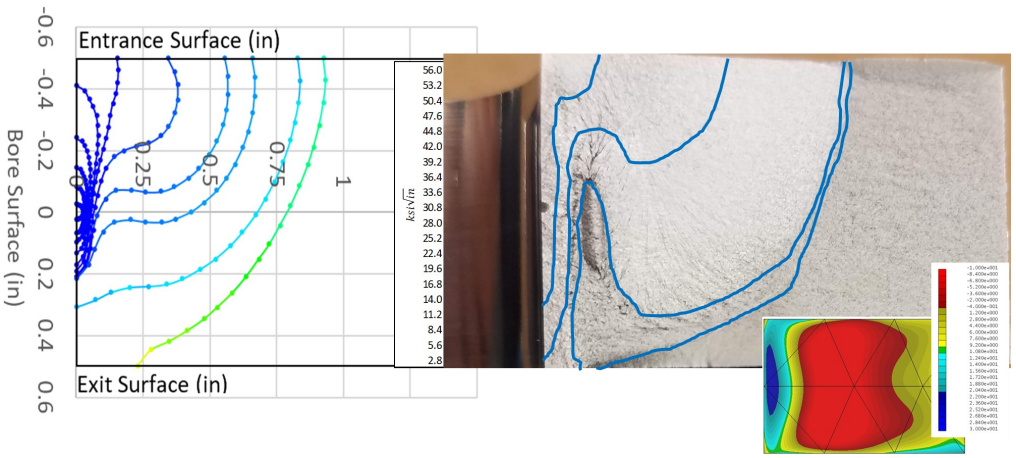
The validation testing committee concurrently presented topics with the fatigue crack growth analysis methods committee at the workshop, given the significant cross-over that exists between the two committees. The discussions highlighted several test programs as well as brainstorming options for the second round robin. A short summary of the test programs are detailed below.

Short Edge Margin Testing (Evan Ross, USAF): Evan Ross presented his thesis research focused on short edge margin applications (e/D < 2.0) and pre-cracked Cx holes. His overview detailed test results as well as comparisons to reduced flaw size (classic approach) and explicit modeling with BAMF predictions. His research focused on a 2024 aluminum alloy configuration with edge margins ranging from 1.3-2.0. Evan also presented photogrammetry efforts focused on capturing the crack closure behavior of cracks at a Cx hole with the intention of comparing these results to analytical modeling. Evan also presented a summary of his thesis at the 2019 USAF ASIP conference.

Geometrically "Large" Coupons:



As a follow-on to previous work, Jacob Warner presented recent test results, fractography, and analytical predictions for geometrically "large" coupons. Part of the difficultly with the Cx hole problem is the significance of the residual and applied stress gradients near the hole. Both gradients are very steep, which creates issues for measurements and life correlations. In an effort to minimize the impact of the gradients and increase the understanding of the residual stress near the hole, geometrically "large" coupons were developed to accomplish residual stress measurements and fatigue testing. The current phase of the effort build upon previous residual stress measurements and focused on experimental testing and fatigue crack growth predictions. As a result of the unique residual stress field, the crack path was quite tortuous, providing a great framework to evaluate crack growth life predictions with multi-point fracture mechanics techniques.



POC: Mr. Jacob Warner (USAF A-10 ASIP); jacob.warner@us.af.mil

Committee Spotlight

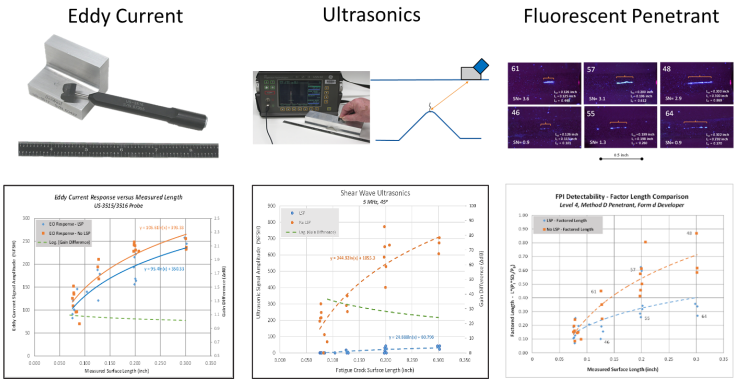
Nondestructive Inspection (NDI)

As the ERSI Working Group continues to push the state-of-the-art, the impacts of ERS on the array of Non-Destructive Inspection (NDI) techniques becomes of greater and greater importance. In an effort to develop additional synergy this year the NDI and Data Management/QA committees meet together to discuss how their individual areas of expertise can be combined to move ERSI faster towards its goal of a more holistic methodology for implementation. Mr. Babish has made the NDI and NDT areas of his implantation philosophy a focal point, as he spoke of them being of greatest concern in his 2017 ASIP Conference Panel presentation. Those leading the NDI and QA/Data Management committees have taken this concern very seriously and at this year's ERSI Workshop they meet together during the break-out sessions to discuss roles and responsibilities, key areas of focus, and future programs.

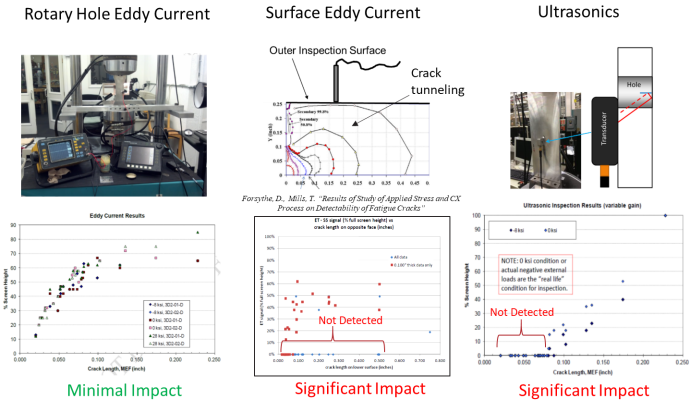
Review of Current Programs

Three main programs were briefed at this year's ERSI Workshop from the NDI Committee. They include the impacts of Laser Shock Peening (LSP) and the Cold Expansion (Cx) process on Eddy Current, Ultrasonics, and Florescent Penetrant. The two images show a summary of that work. This work provides vital information for each weapon system as they look to implement NDI techniques in locations where there are known engineered residual stress fields.

Laser Shock Peening



Hole Cold Working: Eddy Current, Ultrasonics



Addressing the Gaps in the State-of-the-Art

- Quantifying the UT "Dead Zone"

From the Ultrasonics work performed at Cxed holes a signal "Dead Zone" has been documented. In this zone there is a significant reduction in detectability and thus additional work is being performed to investigate the causes of this limited detectability zone and to define updated UT Probability of Detection (POD) correction factors that can be applied at Cxed holes. These corrections are planned to be documented in later revisions of the NDI Structures Bulletin (EN-SB-008-012)

- Effects of Fastener Installation on UT Detectability

In addition to the Cx process causing this UT "Dead Zone" it is possible that high interference fit fasteners, such as Taper-Loks and Hi-Loks cause a similar zone to be developed. Additional UT work is being pursued.

- Effects of Surface ERS Treatments on NDI Methods

Laser Shock Peening (LSP), and Low Plasticity Burnishing (LPB) are areas of additional focus for the NDI team, in order to quantify their effects on UT and FPI, in both aluminum and titanium alloys.

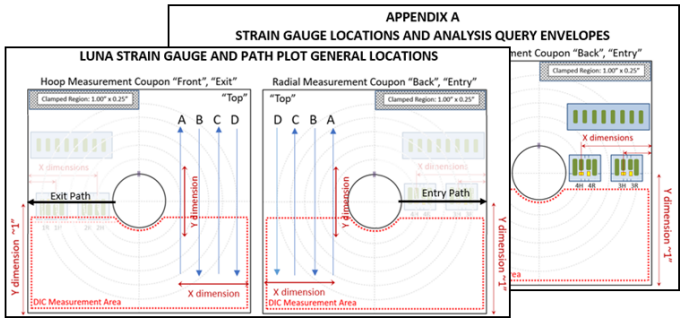
POCs: John Brausch (john.brausch@us.af.mil), Ward Fong (Ward.Fong@us.af.mil)

Residual Stress Process Simulation

Committee Spotlight

The Process Simulation Committee focused on two main areas for the workshop: Material Testing and the Process Simulation Round Robin. The discussions primarily focused on providing an update on these focus areas as well as lessons learned from past efforts.

Coupon Name	Target Applied Expansion Level	Sleeve Orientation (0° = vertical)	Measured Starting Hole Diameter (inch)	Measured Plate Thickness (inch)	Mandrel Major Diameter (inch)	Sleeve Thickness (inch)	Final (Post-Ream) Hole Diameter (inch)
"2024-L2" 2024-Cx-DIC/LUNA/XRD/CM/SG-02-L2	3.16	10.0°	0.4775	0.253	0.4684	0.0120	0.5000
"2024-H1" 2024-Cx-DIC/LUNA/XRD/CM/SG-03-H1	4.16	-1.2°	0.4743	0.254	0.4697		
"7075-L1" 7075-Cx-DIC/LUNA/XRD/CM/SG-01-L1	3.16	3.2°	0.4769	0.252	0.4684		
"7075-H1" 7075-Cx-DIC/LUNA/XRD/CM/SG-03-H1	4.16	-9.5°	0.4741	0.251	0.4697		

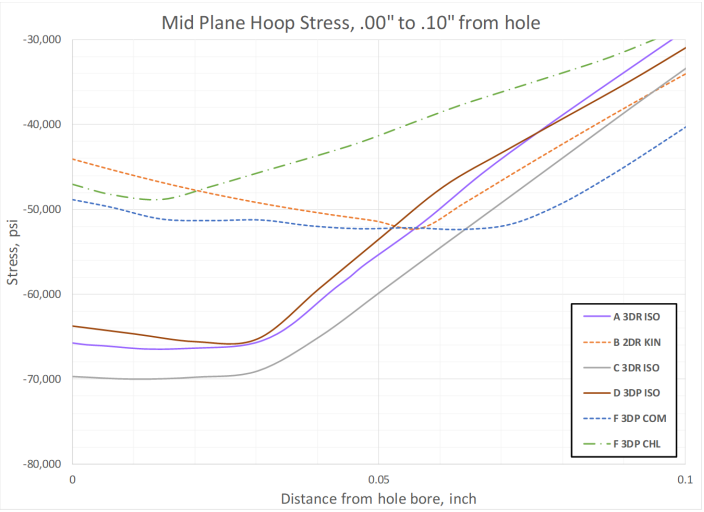


Material Testing Updates:

The Process Simulation committee has applied lessons learned from 2024 testing to the 7075 testing. Test coupon cross-sections were changed from the ASTM 606 cylindrical design to a rectangular design and dual clip gauges were used. The change in cross-section made it easier to detect bending or rotation during testing. Initial testing showed strain measurement divergence starting at ~1.5% strain. This led to a change to shorter coupon length. A piston guide for compressive loads was designed and manufactured. Relatively uniform compressive strains can be measured up to 2% and clip gauges with a higher limit are being installed. 1-cycle tests will be completed following committee discussion of appropriate test levels.

Process Simulation Round Robin:

Additional submissions for the previous round robin continue to be received. Similar material models were used, yielding broadly comparable results. Bore hoop stress range from –30 to –70 ksi over all models and locations. Comparisons to X-ray diffraction appear to diverge in the far field region. The committee still needs to evaluate the radial strain discrepancies. See left for a sample of data from the round robin testing. The round robin for analysis of the 2"x2" coupon cold expansion is still opened to anyone with interest, using coupons shown at the upper right.



We look forward to providing the ERSI working group updates on these topics, and other items of interest (general process simulation data set comparison, correlation metrics, validation) at the workshop next July!

As a final note: The Process Simulation Committee has been fairly successful at holding regular monthly meetings. The chair would like to thank the PSC members for their participation. Meetings are held the 3rd Friday of each month, at 11am EDT (8am PDT); contact a PSC member for details, we'd love to have you on a call!

POC: Mr. Keith Hitchman (FTI); Keith.Hitchman@pccairframe.com

Committee Spotlight

Residual Stress Measurement

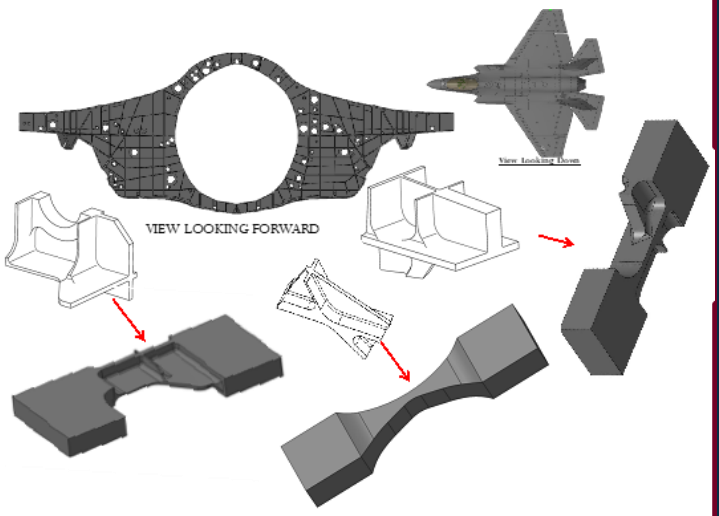
Coming into the workshop, the Residual Stress Measurement Committee discussed their focus on revisiting their goals and ensuring they aligned with the overarching goals of ERSI. One important goal which received emphasis was to enhance the documentation of past and on-going work related the residual stress measurement and ERSI initiatives. The group collectively developed and presented a summary of these related projects at the workshop.

Some important ongoing/recently completed projects include:

- Textured & Textured Rings and Plugs
- LSP of Various Material Forgings
- 2 in. x 2 in.. Cx Coupons
- A-10 ASIP Modernization
- Steel Cx Holes

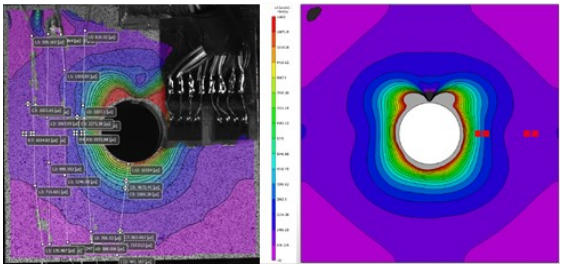
LSP of Various Forgings:

Work completed on LSP of two different forgings is ongoing. The two materials being worked are 7085 and Ti6Al4V. Research for 7085 has resulted in over 60 different measurements using the contour method, including many replicates. This has allowed for the development of a robust residual stress database for a range of geometries. Work completed on Ti6Al4V forgings will result in quantifying residual stress in three different geometries via the contour method. Those three geometries are shown at right.



2x2 Cx Coupon Round Robin:

Additional progress has been accomplished for the 2x2 Cx coupons since the last update. Additional effort has focused on 2024-T351 and 7075-T651 aluminum alloys at “low” and “high” applied expansion levels. The goal is to quantify surface residual stresses while performing the Cx process using at least eight different methods. The vision is to utilize the data for validation of FEA simulation.



A-10 ASIP Modernization:

The A-10 ASIP group continues to work with Hill Engineering to measure residual stress magnitudes and distributions for various conditions. Additional refinement of near surface measurements is in work with the ultimate goal of refining the understanding of residual stress at Cx holes utilizing a complimentary set of different measurements. Ultimately, these results will help to characterize the key factors that impact residual stress at Cx holes and support the appropriate inputs for damage tolerance analysis (DTA).

Steel Cx Holes:

FTI and Hill Engineering are working together to research the effects of cold working holes in steel. The goals are to quantify the residual stress in the steel Cx specimens, and to compare the residual stress measurement results to the process model.

POC: Dr. Mike Hill (Hill Engineering, LLC); mrhill@hill-engineering.com

Data Management and Quality Assurance

Committee Spotlight

Validated Quality Assurance (QA) and Nondestructive Evaluation (NDE) methods continue to be a key focus on the path to “full credit” for engineered residual stresses. Recently, Kaylon Anderson took the lead role for the Data Management and Quality Assurance (DM&QA) committee and has refocused the groups attention on the key gaps that must be addressed to reach “full credit”. During the recent workshop key aspects of DM&QA were discussed, as well as introducing the topic of Nondestructive Evaluation (NDE) as a new focus area for their committee. Given the significant cross-over of this topic with the NDI committee, the two committees are closely working together to address this focus area.

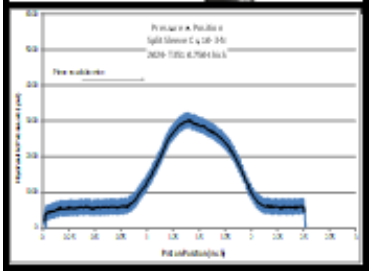
Quality Assurance:

In-process QA to validate the engineered residual stress was attained as intended was a primary discussion point during the workshop. Standard QA approaches such as the FTI go / no-go gauges as well as new technologies in development were reviewed. These new technologies included the following:

FastenerCam (TRI-Austin): This technology has been in development for several years and TRI-Austin is currently working on a production ready system. FastenerCam leverages the out-of-plane surface deformation associated with the Cx process to correlate to the beneficial compressive residual stress. This technology can be leveraged during the production and sustainment phases of a weapon system.

Instrumented puller (FTI): FTI has developed an instrumented puller to capture puller force data during Cx processing and establish a digital thread for Cx. FTI is also working on software to correlate pressure force data to Cx effectiveness, providing additional QA tools to ensure process compliance and provide the data stream necessary to empower ASIP offices.

Maintenance Data Spatial Positioning (DSP) System (Hill Engineering, FTI, NLign): In response to a USAF Rapid Innovation call, the Hill Engineering team is developing an integrated maintenance system to collect the full digital thread for Cx, including the process effectiveness (FTI instrumented puller), location compliance, and automated data population into the ASIP maintenance data system (NLign). This program is intended to address the QA needs for Cx on the path to “full credit”.



Nondestructive Evaluation:

NDE is a newer consideration for the DM&QA team, however, is critical to validate a stable engineered residual stress throughout the sustainment phase of fleet management, a key requirement to achieve recurring inspection interval “full credit”.

NDE for Cx holes (AFRL, Hill Engineering, SwRI): A new program is underway to develop NDE technologies specifically focused on the unique attributes of a Cx hole. As this program matures additional details will be shared with the ERSI community.

POC: Mr. Kaylon Anderson (USAF A-10 ASIP); kaylon.anderson@us.af.mil

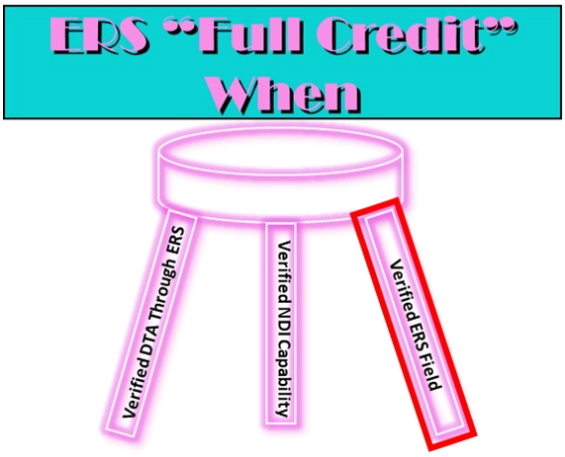
Committee Spotlight

Risk Analysis and Uncertainty Quantification

The Risk Analysis and Uncertainty Quantification (UQ) Committee presented two main topics at the 2019 ERSI Workshop. These included an overview of Mr. Dallen Andrew's Ph.D. dissertation topic, which is focused on the development of a statistically derived residual stress allowable methodology, and a summary of an uncertainty quantification exercise that was executed over the 2019 period. This UQ work was performed by Dr. Joe Yurko (at the time of work performed at Arconic, now at University of Pittsburg) and Mr. Gavin Jones (Smart UQ). The work that they presented demonstrated a methodology and the results shown are not representative of the stress fields developed.

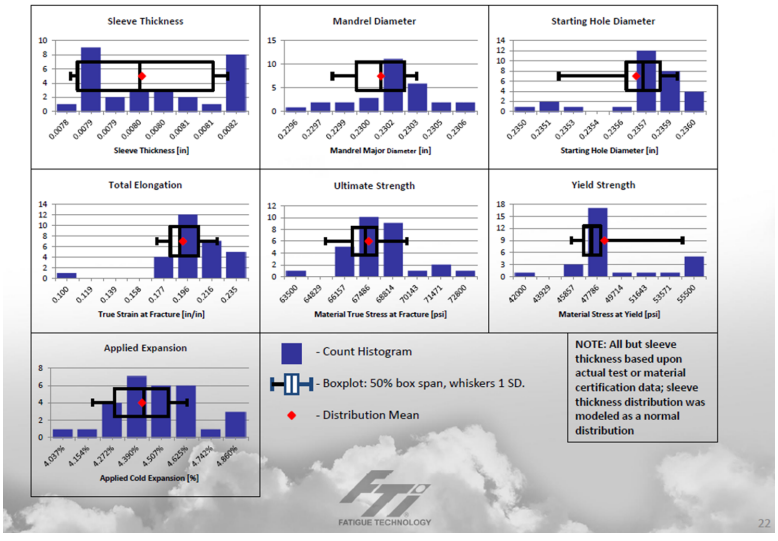
A Spatial Statistics Approach for Utilizing 2D Residual Stress Fields in a Fatigue Crack Growth Analysis (Dallen Andrew, Hill Engineering)

The development of a statistically-based residual stress field allowable has been discussed within the ERSI Working Group for a few years now and Mr. Dallen Andrew has taken this as his dissertation research topic. The purpose of this research is to characterize 2D spatial residual stress fields, developed by the SSCx™ process by (1) determining the appropriate binning method and (2) by determining the appropriate filtering method to be used prior to the calculation of the resultant response surface. Through this work it will be possible to calculate a residual stress response surface that meets a confidence and reliability requirement, similar to that which is required for material allowables.



Uncertainty Quantification Methodology Development Using FEA-Based Residual Stress Fields

A series of 29 models were provided to the RA/UQ committee which varied seven different model input parameters. Dr. Yurko was able to use the outputs from these models to demonstrate an uncertainty quantification methodology, showing correlations and dispersions amongst each dataset. Mr. Gavin Jones was also able to use the datasets to develop a Gaussian Process Surrogate Model, a linear regression model, and a GP Emulator to produce a Global Sensitivity Analysis, showing that results were directly dependent upon the sleeve thickness. The work contained herein is to be rerun due to an error in the outputs provided to the analysts.



POC: Mrs. Laura Hunt and Mr. Lucky Smith (SwRI); Laura.Hunt@swri.org, Luciano.Smith@swri.org

Announcements

- **Recent and Upcoming ERSI-related events:**
  - ASIP Conference, Dec. 2-5, 2019 in San Antonio, Texas
  - ASTM Committee E08 Meeting - Workshop on Incorporating Residual Stress into Structural Design and Sustainment, May 13, 2020 in Boston, Massachusetts
- **ERSI 2020 Venue Change**
  - The 2020 ERSI Workshop will be hosted at the Wright Brother Institute (444 location) in Dayton, OH the week of July 27th-31st.
- **Change in ERSI Executive Committee**
  - We wanted to recognize Mr. Dallen Andrew for his tremendous support of the ERSI Working Group since its inception. Dallen has been an instrumental part of the organizational group supporting the logistics of each workshop, the development of the Screamer, and many of the behind the scenes tasks that keep things moving forward. As many of you know, Dallen is pursuing his doctorate degree focused on spatial statistics characterization of residual stresses. In order to dedicate enough time to his research, Dallen is stepping down from his role as an ERSI organizer. From the entire ERSI Working Group, we say thank you to Dallen for his tremendous contribution to the success of ERSI and look forward to his continued contribution to several key committees.
- **ERSI Committee participation and ERSI Workshop attendance**
  - 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 in one of the committees, please refer them to contact the ERSI Organizers or applicable committee chair.
  - REMINDER: While we do encourage people to join in the different committees freely, participation in the ERSI Working Group and Workshop is by invitation only from the ERSI Organizers. If you would like to participate in the ERSI Working Group or attend the 2020 Workshop, please contact the ERSI Organizers and we will review your request. Active participation and involvement in at least one of the committees is one of the metrics used to assess Workshop attendance.

Announcements

- **ERSI contact info:**
  - We've recently established a new email address for ERSI related communication. If you ever have questions, suggestions, or complaints please let us know by sending an email to organizers@ersigroup.org. Any feedback on the ERSI workshop, committee lead roles, or any other topic is always appreciated.

- **New ERSI website in development!**
  - We're currently in the process of developing a new ERSI specific website.
  - We want to thank SwRI for their tremendous hospitality supporting the current ERSI website.
  - The new website will be up and running early next year.
  - In the meantime, you can continue to utilize the existing website at https://member-ersi.swri.org.

We Need You!

We would like to have input from YOU for the next publication of the ERSI Screamer!

Please send us an email to organizers@ersigroup.org and tell us what residual stress related problems you are facing, which ones you have solved, or which ones you wish you could solve. And of course you can also directly contact the appropriate committee chair.

Remember, the only way the vision and purpose of ERSI will be realized is by consistent contributions from the ERSI community.

Who is ERSI?

ERSI

Stress Map

HILL ENGINEERING
Predict. Test. Perform.

APES, INC.
analytical processes / engineered solutions

AFGROW.NET

FTI FATIGUE TECHNOLOGY

LOCKHEED MARTIN

ARCONIC

BOEING

Booz | Allen | Hamilton
strategy and technology consultants

NRC·CNRC

NORTHROP GRUMMAN

L3 HARRIS

STRESSCHECK

Los Alamos NATIONAL LABORATORY EST. 1943

ATRI AUSTIN

SMARTUQ Quantify Every Uncertainty.

SwRI

Constellium

CURTISS WRIGHT Surface Technologies

PROTO MANUFACTURING

FULCRUM ENGINEERING, LLC

GTC MACHINING

Coventry University

MERC MERCER ENGINEERING RESEARCH CENTER
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