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ERSI SCREAMER

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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 across subcommittees. A brief description of the who, what, and why of ERSI is included here.

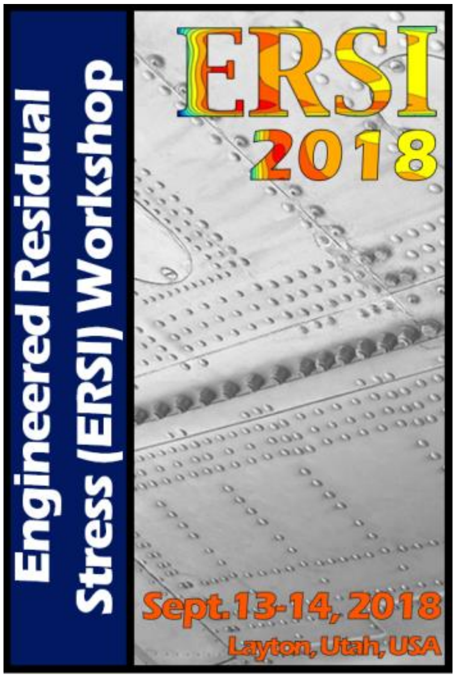
Sponsoring Organization: This working group is sponsored by the United States Air Force (USAF) Aircraft Structural Integrity Program (ASIP) under the direction and guidance of Mr. Chuck Babish.

Purpose:
1.To identify and lay out a roadmap for the implementation of engineered deep residual stress which can be used in the calculation of initial and recurring inspection intervals for fatigue and fracture critical aerospace components.
2.To highlight gaps in the state-of-the-art and define how those gaps will be filled.
3.Then to define the most effective way to document requirements and guidelines for fleet-wide implementation.

Vision: Within 3-7 years have developed 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. Then move from there to other deep residual stress inducing processes, like Laser Shock Peening and Low Plasticity Burnishing.

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

Subcommittee	Chair(s)
INTEGRATOR	Dr. Dale Ball (Lockheed Martin), Dr. TJ Spradlin (USAF AFRL), & Dr. Mark Thomsen (USAF A-10 SPO)
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	Dr. Carl Magnuson (TRI-Austin)
NON-DESTRUCTIVE INSPECTION	Mr. John Brausch (USAF AFRL)
RISK ANALYSIS & UNCERTAINTY QUANTIFICATION	Ms. Laura Hunt (SwRI) & Mr. Lucky Smith (SwRI)
RESIDUAL STRESS MEASUREMENTS	Dr. Mike Hill (Hill Engineering)



3rd Annual ERSI Workshop

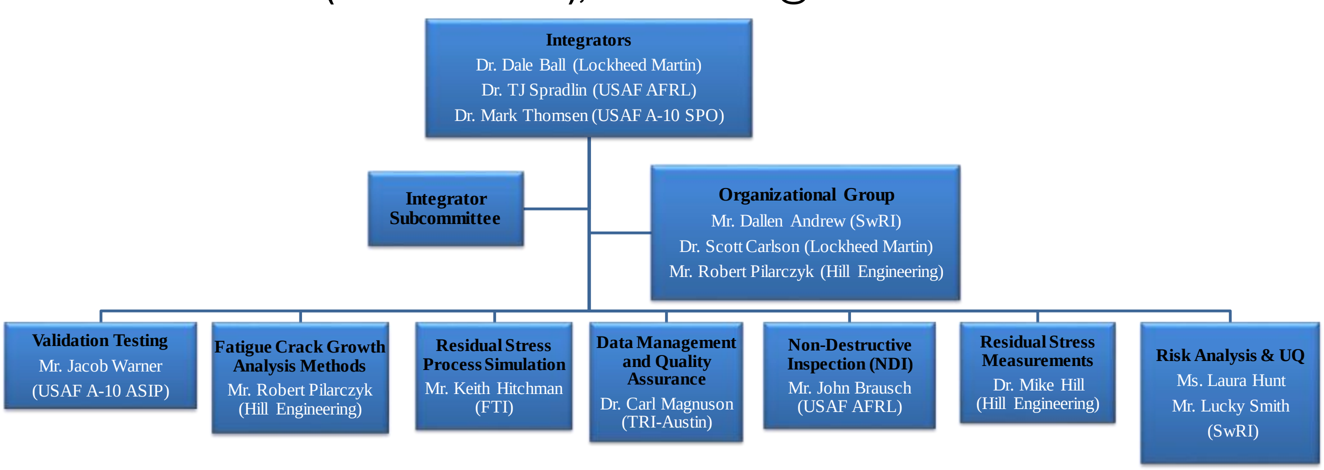
The 2018 ERSI Workshop was held at the Layton Weber State University campus on September 13-14, 2018. Attending were representatives of all three major airframe OEMs, both the USAF and USN, and ASIP managers from A-10, F-16, F-15, KC-135, and B-1. In addition we had representation from our industry partners and academia.

This year's Workshop focused on progress reports in seven key focus areas around the implementation of governing policy for the inclusion of engineered residual stresses in durability and damage tolerance analysis. These included, Fatigue Crack Growth Analysis Methods, Process Simulation, Validation and Verification Through Test, Impacts to Non-Destructive Inspection Method, Quality Assurance and Data Management, Residual Stress Measurement, and Risk Analysis & Uncertainty Quantification.

ERSI Involvement as of September 2018
Total Individuals within the Working Group: **110**
Countries Involved: **5**
DoD Organizations: **3 (+ FAA)**
National Laboratory: **2**
Universities: **5**
OEMs: **3**
Industry Partners: **19**
USAF ASIP Managers: **6**

Key discussion points included the development of an upcoming USAF Structures Bulletin focusing on the inclusion of engineered residual stresses in fatigue crack growth analysis methods, a residual stress determination methods round robin for the quantification and cross-comparison of residual stresses at a Cold Expanded (Cx) hole condition, the development of enhanced material properties for more accurate process simulation, results of multiple analytical predictions of fatigue crack growth at a Cx hole condition, and a reproducibility uncertainty quantification effort focused on the contour method. The A-10 program office has provided significant funding and manpower contributions to all of the listed above efforts and represents the only organized programmatic resource for ERSI. It is hoped that other System Program Offices (SPOs), OEMs, academia, industry patterns, and other US government funding sources will also provide financial and manpower support to assist in helping reach the mission and vision of ERSI, to develop and implement a more holistic approach to the inclusion of engineered residual stresses for the calculation of initial and recurring inspection intervals. The organizational structure of ERSI is shown below.

POC: Dr. Scott Carlson (Lockheed Martin); scott.carlson@lmco.com

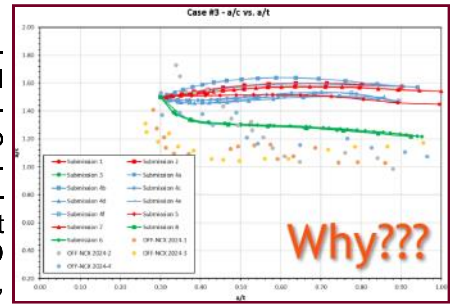


Subcommittee Spot

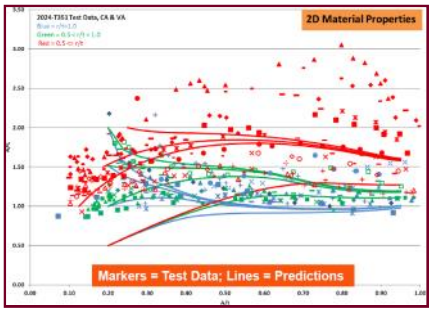
Fatigue Crack Growth Analysis + Testing

A variety of topics were covered in this year's meeting—a brief summary of some are provided below.

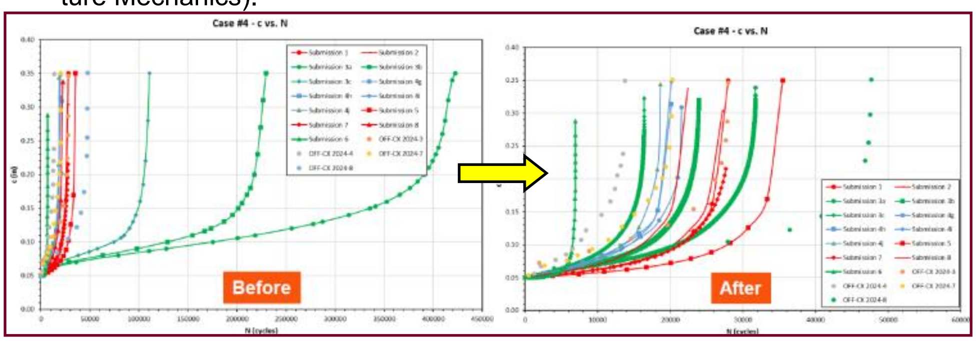
Round Robin for Cx Holes



Purpose was to identify the random and systematic uncertainties associated with Damage Tolerance Analyses (DTAs) that incorporate residual stresses produced by Cx of fastener holes. The main focus became to investigate the consistency, strengths and weaknesses of each method to define best practices moving forward. This last year was spent trying to answer some of the "why's" of the different results, such as variation in aspect ratio (see image at right), 1D vs. 2D material properties (see image at left), and some significant over-predictions.



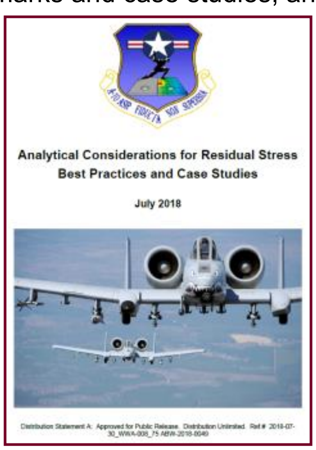
This year of "why's" has been very fruitful with significant improvements made to the analysis techniques used — see the initial results compared to the most recent in the image below. A journal article is in work with a white paper accepted to 19th International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics (42nd National Symposium on Fatigue and Fracture Mechanics).



In addition, there is a follow-on Round Robin effort being planned, with one current candidate being geometrically "large" coupons. Part of the difficulty with a CX hole is the significance of the applied stress gradients near the hole. These 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 have been developed to accomplish RS measurements and fatigue testing.

Best Practices Document

The purpose of this document was to share best practices, lessons learned, analysis methods; document benchmarks and case studies; and compliment other policy documents. The organization is described below:

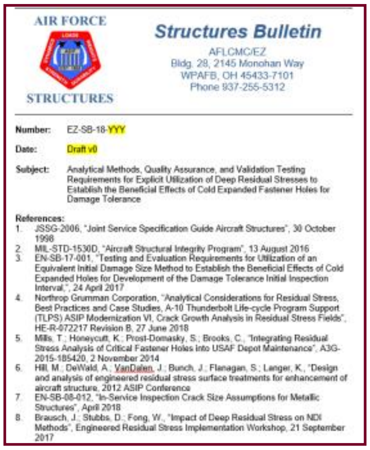


- **Chapter I Introduction**: An introduction to fatigue, damage tolerance, and residual stress
- **Chapter II Analytical Processes:** An overview of analytical processes, input data (such as material models and loading), and the performance of multi-point fracture mechanics when coupled with FEA
- **Chapter III Other Considerations:** Covers factors influencing residual stress and the associated uncertainty, such as factors influencing residual stress, the variability in residual stress data, necessary validation testing, NDI, quality assurance, risk management, or certification considerations
- **Chapter IV Benchmark Cases:** Reviews handbook solutions and ERSI round robin results
- **Chapter V Case Studies**: Currently contains a laser shock peening case study and Cx hole case study

The publicly released version was available July 2018. However, the document is only as good as the inputs provided by the community. We have input needs from the ERSI community related to: Process modeling best practices, other analysis methods, factors that influence residual stress, risk assessment considerations, certification considerations, procurement vs. sustainment considerations, or case studies.

Fatigue Crack Growth Analysis + Testing (cont'd)

Subcommittee Spot


AIR FORCE
STRUCTURES

Structures Bulletin
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Number: EZ-SB-18-YYY
Date: Draft v0
Subject: Analytical Methods, Quality Assurance, and Validation Testing Requirements for Explicit Utilization of Deep Residual Stresses to Establish the Beneficial Effects of Cold Expanded Fastener Holes for Damage Tolerance

References:
1. JSSG-2006, "Joint Service Specification Guide Aircraft Structures", 30 October 1998
2. MIL-STD-1530D, "Aircraft Structural Integrity Program", 13 August 2016
3. EN-SB-17-001, "Testing and Evaluation Requirements for Utilization of an Equivalent Initial Damage Size Method to Establish the Beneficial Effects of Cold Expanded Holes for Development of the Damage Tolerance Initial Inspection Interval,", 24 April 2017
4. Northrop Grumman Corporation, "Analytical Considerations for Residual Stress, Best Practices and Case Studies, A-10 Thunderbolt Life-cycle Program Support (TLPS) ASIP Modernization VI, Crack Growth Analysis in Residual Stress Fields", HE-R-072217 Revision B, 27 June 2018
5. Mills, T.; Honeycutt, K.; Prost-Domasky, S.; Brooks, C., "Integrating Residual Stress Analysis of Critical Fastener Holes into USAF Depot Maintenance", A3G-2015-185420, 2 November 2014
6. Hill, M.; DeWald, A.; VanDalen, J.; Bunch, J.; Flanagan, S.; Langer, K., "Design and analysis of engineered residual stress surface treatments for enhancement of aircraft structure, 2012 ASIP Conference
7. EN-SB-08-012, "In-Service Inspection Crack Size Assumptions for Metallic Structures", April 2018
8. Brausch, J.; Stubbs, D.; Fong, W., "Impact of Deep Residual Stress on NDI Methods", Engineered Residual Stress Implementation Workshop, 21 September 2017

Draft Structures Bulletin

- Currently under USAF internal review
- Titled: "Analytical Methods, Quality Assurance, and Validation Testing Requirements for Explicit Utilization of Deep Residual Stresses to Establish the Beneficial Effects of Cold Expanded Fastener Holes for Damage Tolerance"

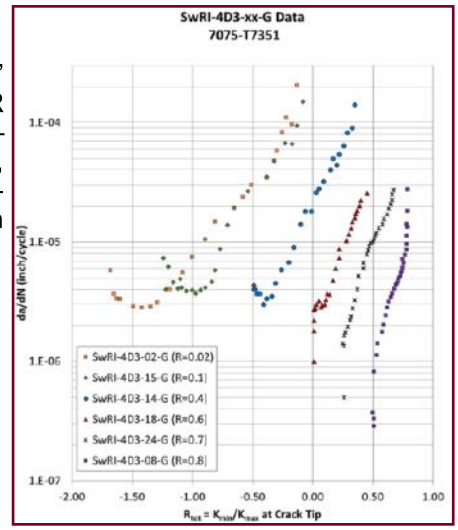
Engineering Implementation of Residual Stress

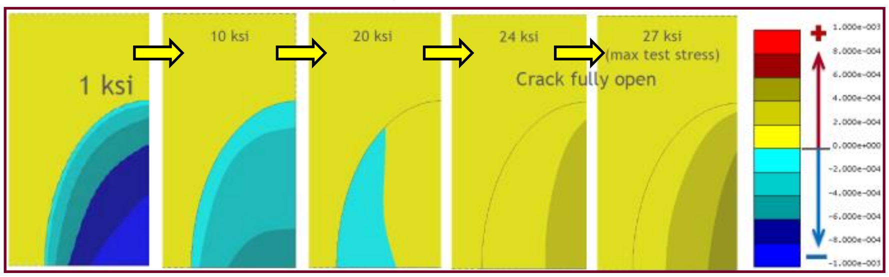
Topics covered included:

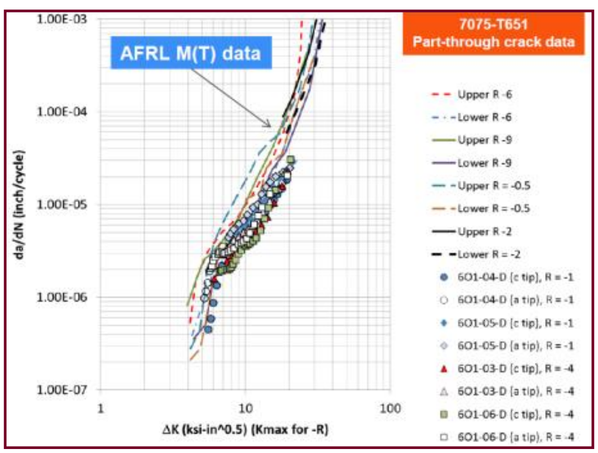
- Post-Service vs. New Manufacture Coupon Residual Stresses
  - How do we account for load history, environmental effects, or initial stress shakedown in our analyses?
- Crack Tip Plasticity Interaction: 2024-T351 and 7075-T651
- Non-Dimensional Residual Stress -The Hodge Podge

Crack Closure Effects

Modeling Closure: It has been observed from previous testing that the 'dip' in the da/dN curve occurs for cracks < 0.1 inch at negative R_{tot}, while for R > 0, the 'dip' is not present, which corresponds to an R_{app} = 0.6, 0.7, 0.8 — see image at right. There is work underway to model this closure effect, using displacement normal to the symmetry plane with positive displacement meaning crack opening. See FEA images below for the change in stress at the hole with increasing load.







Negative-R Test Data

Limited -R fatigue crack growth rate testing was conducted to compare corner crack FCGR data to AFRL historical data—see figure at left. These were center cracked M(T) panels (to match what was tested by AFRL) as well as part-through crack "dog-bones", in both 2024-T351 and 7075-T651. There is additional -R testing that is upcoming for the USAFA and A-10 ASIP, where it will be attempted to get detailed measurements in bore to get thru thickness rate data.

<u>Conclusion:</u> There has been significant collaboration within the Analysis Methods Subcommittee — thanks to those individuals that have provided inputs. We are putting out a call for additional inputs from the ERSI community for inclusion into the Best Practices Document.

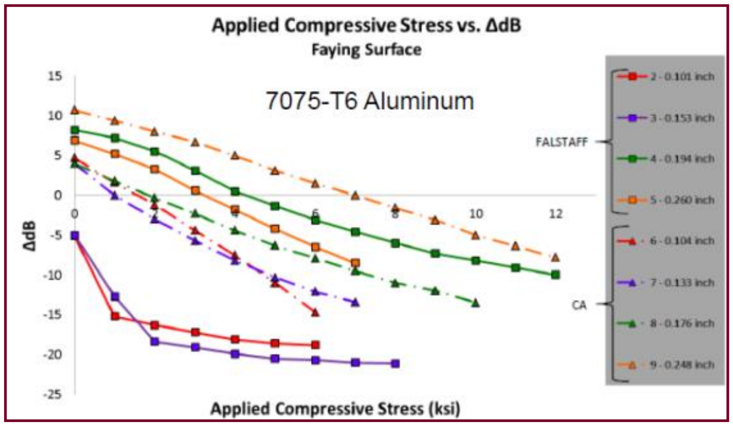
POCs:

- **Mr. Robert Pilarczyk (Hill Engineering); rtpilarczyk@hill-engineering.com**
- **Dr. Tom Mills (AP/ES); tmills@apesolutions.com**

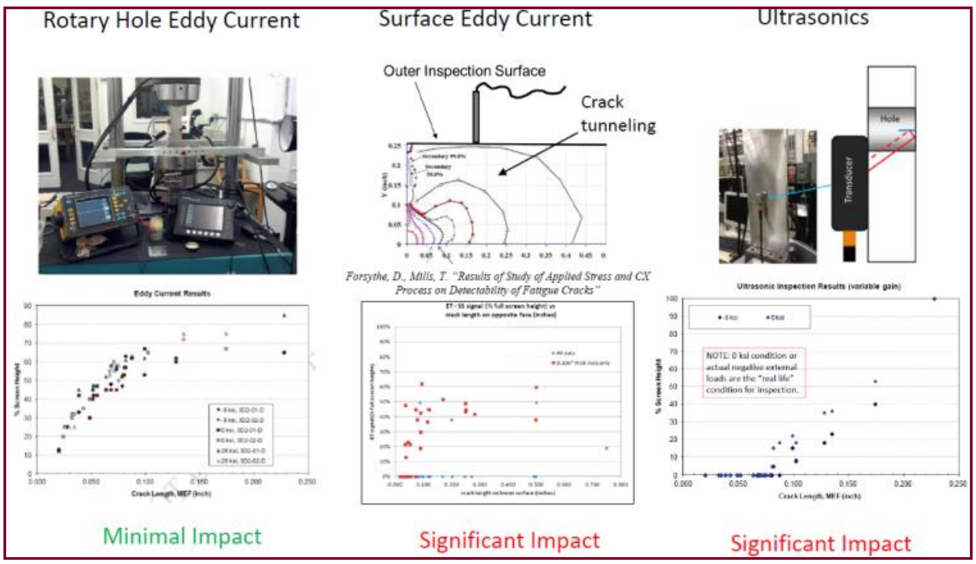
Subcommittee Spot

Nondestructive Inspection (NDI)

Since the inception of the ERSI working group in 2016, the NDI Subcommittee has been evaluating existing literature and executing a series of experiments to quantify the impact of residual stress treatments on detectability of fatigue cracks using conventional inspection methods. It has been well documented that there is a significant impact of the ultrasonic response from fatigue cracks under applied compressive stress, approximately ~6dB (50%) signal reduction per 4ksi applied compressive stress—see figure at right.



In a previous edition of the ERSI Screamer, the effects of laser shock peening (and associated compressive residual stresses) on eddy current, ultrasonic testing (UT), and fluorescent penetrant inspection methods were reported. In the image below, the effect of cold expansion of holes (and associated compressive residual stresses) on rotary hole eddy current, surface eddy current, and ultrasonic inspection methods can be seen. Specifically for UT, it was also reported that there is a ultrasonic “dead zone” in the presence of compressive residual stresses at a cold expanded hole—see image below. This dead zone is proportional to hole diameter, but the data scatter suggests there are other influencing factors. The upper bound of the dead zone estimates can be used to correct the UT Probability of Detection (POD) estimates for Cx holes. In order to manage this dead zone, ultrasonic inspections must be designed to interrogate beyond the tangency of the hole.



As part of the subcommittee meeting at the ERSI workshop, current tasks were refined in order to address areas of this “dead zone” challenge.

Priority 1 is to quantify the UT dead zone in Cx holes and correlate to thickness and hole diameter. For this task, a need from the ERSI Working Group are stress profiles from previous Cx programs.

Priority 2 investigates the impact of Taper-Lok fastener installation on ultrasonic fatigue crack detectability, with empirical measurements of UT response to be accomplished under an upcoming program effort. For this task, an existing need from the ERSI Working Group is to develop a model of the Taper-Lok stress field.

Lastly, Priority 3 focuses on characterizing the impact of laser peening on titanium, with the current plan to integrate measurements into upcoming aircraft qualification programs.

The NDI Subcommittee is actively seeking opportunities for collaboration in this research areas particularly with planned or ongoing programs generating specimens representing these configurations.

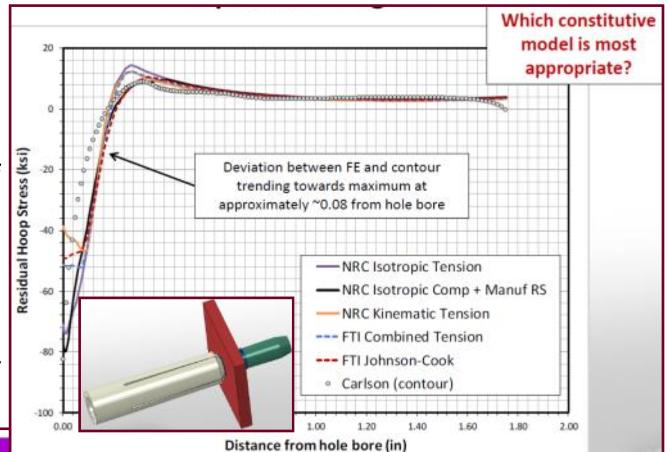
POCs:

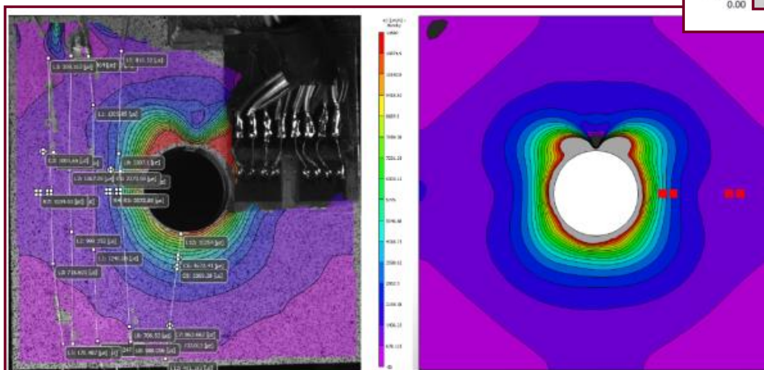
- **Mr. John Brausch (USAF—AFRL), john.brausch@us.af.mil**
- **Mr. Ward Fong (USAF-HILL AFB NDI); ward.fong@us.af.mil**

Residual Stress Process Simulation

Subcommittee Spot

As a follow-on to the last edition of the ERSI Screamer, the material model evaluation program is still on-going. The testing was completed in Spring 2018 and was based upon ASTM E606, with FTI fabricating 10 samples for each orientation, T, L and 45° specimens from the same lot of material as the 2” x 2” coupons. NRC was able to work through several issues that popped up to provide an excellent body of data – see figure at right. Tasks still underway include isolating the current investigation to orthotropy and also non-stabilized cyclic loading capturing reverse-yield behavior (2024 currently, 7075 to follow).



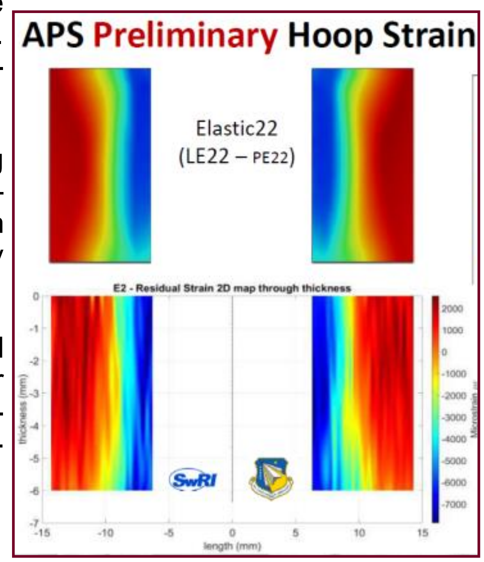


DIC Hoop strains

FEA Hoop strains
Chaboche Hardening (Clausen)

The Process Simulation Subcommittee continues to work through a significant residual stress quantification and validation program using a set of 2"x2" Cx specimens. It is known that the quantification of residual stresses through process simulation is a critical path for future ERSI realization, and that there is limited open literature on cross-comparison of residual stress measurement methods for Cx holes. The purpose of the effort is to perform experiments to capture surface and through-thickness strains using multiple techniques for FEA process simulation validation and comparison. This would provide the potential to complement through-thickness techniques with surface techniques for a more accurate understanding of the complete residual stress field.

The surface measurement techniques being used at both the entrance and exit side of hole are: Digital Image Correlation (DIC), Fiber Optics (LUNA), Strain gages, and X-ray Diffraction (XRD). Currently, some of the tabular surface strain measurement data are available for correlation from the LUNA system and from the strain gages. See the DIC results and an FEA result of hoop strains in the image above.



The volume (through-thickness) measurement techniques being used for this program are: High Energy X-ray Diffraction (APS HE-XRD) by Argonne National Labs, High Energy X-ray Diffraction (CHESS) by Cornell, Neutron Diffraction at Coventry University (UK), and the Contour Method by Hill Engineering, LLC.

The group is working on a revised FEA using an NRC-based Chaboche model, with full correlations to follow. The raw data for the volume strain measurements are still being evaluated and reduced, and all results and correlations shown are considered preliminary and may change. A preliminary image is shown at right.

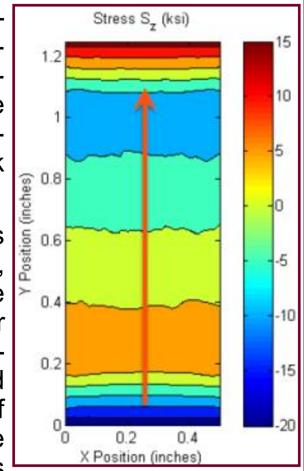
POC: Mr. Keith Hitchman (FTI); khitchman@fatiguetech.com

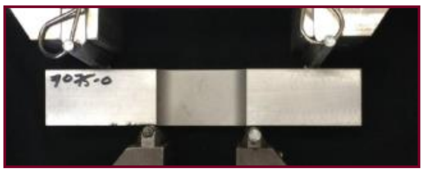
Subcommittee Spot Residual Stress Measurements

A variety of topics were covered in this year's meeting—a brief summary of each is provided below.

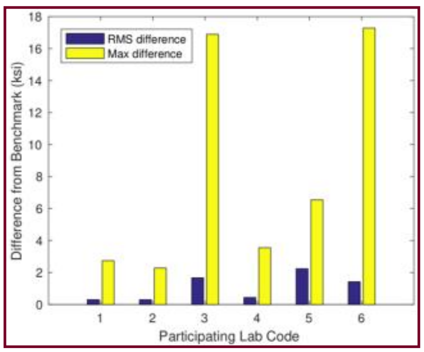
1. Contour method round robin

The purpose of this effort is provide an understanding of the inter-laboratory reproducibility uncertainty associated with the data analysis portion of the contour method. It includes 6 participants, with a mix of industry, government, and academia, and is a multi-phase program of blind analyses where participants don't interact with each other. The group is utilizing samples from a controlled experiment performed by SwRI of an elastic-plastic bent beam (see photo of experimental setup below), which is a prior benchmark problem and classical residual stress experiment used for method validation.



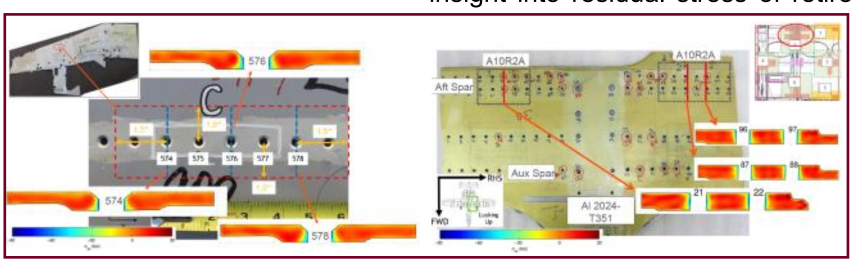


At the end of Phase 1, participants returned results very similar to the benchmark simulation stress field, all given the same input data. The RMS difference with the benchmark was less than 2 ksi—see lower left plot. An example submission is shown in the figure at the right. Phase 2 uses experimental data and that work is nearly complete. Additional results of this will be presented at the 2018 ASIP Conference and the 2019 Society of Experimental Mechanics Conference.

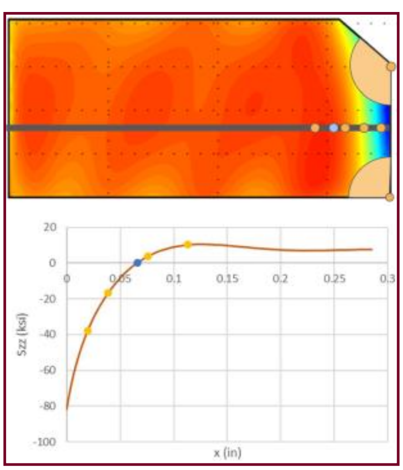


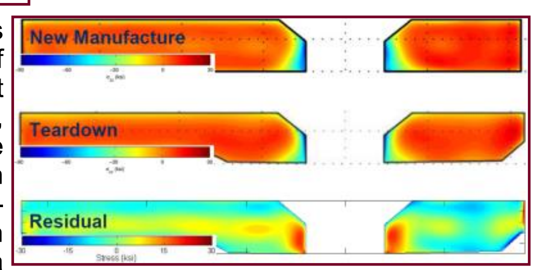
2. Measurements of residual stress at legacy versus new Cx holes

This program was an investigation into cracking and residual stress at Cx holes from retired fleet assets to understand if there is a degradation over time as a result of loading or environment. In incorporates residual stress measurements from both A-10 and T-38 legacy assets, residual stress measurements of newly manufactured specimens that replicate legacy asset configurations, and the comparison of residual stresses between new manufacture and teardown coupons. An extensive program completed which provides insight into residual stress of retired fleet assets, with 300+ residual stress measurements accomplished, with 146 teardown holes and 72 new manufacture holes for the A-10 (near left image) and 57 teardown holes and 33 new manufacture holes for the T-38 (far left image). The results indicate significant residual stress remained in all evaluated teardown locations, with no "missed Cx" locations.



The initial comparisons are complete, which consisted of record residual stress values at discrete locations of 0.125*r, 0.25*r, 0.50*r, and 0.75*r from the hole edge, as well as at the depth of zero-crossing. These initial comparisons also included the mean and standard deviation within a 0.050" radial zone centered at the Cx entry surface and exit surface / countersink knee (if applicable). All the level I locations are identified in the figure at left, with the corresponding line plot below extending away from the hole bore.



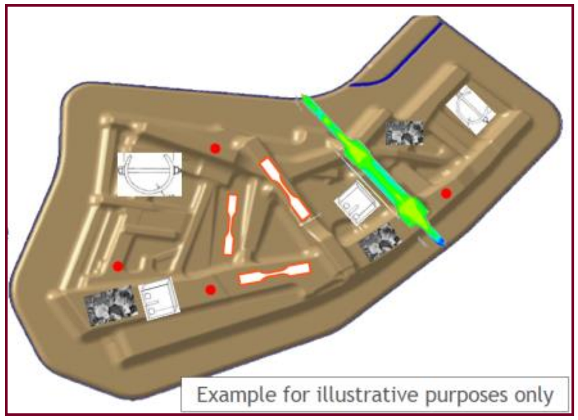


The initial results show comparable stresses observed between teardown and new manufacture coupons with significant overlap (see above image). There is much more work to do, as this program resulted in a wealth of information, with the main focus being how do these results impact fleet management decisions. Results of this effort were presented at that 2018 AA&S and ASIP Conferences.

Residual Stress Measurements (cont'd)

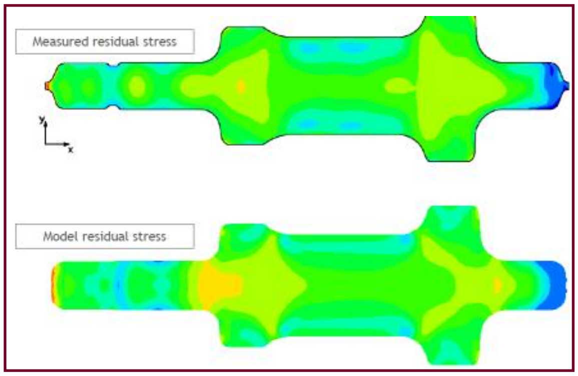
Subcommittee Spot

3. Residual stress quality system



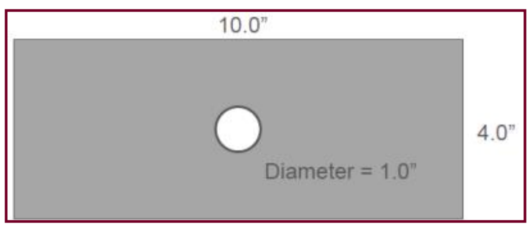
This effort is focused on the role of residual stress in design and manufacture. The historical design approach has been that residual stress is a known unknown, and was removed where possible (thermal or mechanical stress relief). Analysts conservatively managed effects on degradation (fatigue, SCC, creep) utilizing conservative assumptions (i.e., tensile residual stress fields). Components must be inspected, repaired, or replaced, with costs escalating with system age. This approach takes minimal credit for beneficial compressive residual stress.

The emerging design approach is to incorporate residual stress as part of specifications, with the understanding that there are residual stresses in parts, which can be known residual stresses by measurements, models, and validation metrics. This emerging approach include residual stress in materials and process engineering, performs trade studies, and requires a quality program that can directly account for residual stress effects on performance.



Some examples of residual stress related concerns during procurement and design are: tensile residual stress causing premature/unexpected failure, large and/or inconsistent residual stress levels impacting machining, or ensuring presence of beneficial compressive residual stresses. A few example situations are given below that show how this emerging design approach could be used to incorporate residual stress as part of the initial design and analysis.

Example — First Article Qualification:
First articles often require extensive testing to validate critical properties and characteristics such as size/dimensions, chemical composition, mechanical properties, stress-corrosion cracking, defect assessment, or microstructure/grain-flow. Residual stress can be handled similarly—see above right figure that shows a possible approach.



Example — First Article Qualification Validation:
Favorable comparison could be made between measurements and models—see comparison images in above left figure.

While there are methods to include residual stress in product life analysis, there is a need to validate the models to ensure accuracy. Also, quality systems for residual stress should be developed and executed to certify products.

4. Large Cx hole experiments

The objective of this set of experiments is to develop a coupon that scales-up the stress field magnitude and allows for better development and interrogation of the measurement data by having a more shallow stress gradient than is typically seen at a Cx hole. The coupon design needed to feature a large diameter, maximize the length scale of "near-surface" and "near-bore" regions, be long enough to facilitate fatigue testing and wide enough to minimize edge margin effects. The final coupon design is shown in figure above. The experiments are being performed in both 7075-T651 and 2024-T351 material types.

The initial contour method measurements are complete, with results indicating that the residual stresses are consistent with the scaling of geometry and is very consistent specimen-to-specimen. The next set of experimental testing is in work, which includes additional residual stress measurement methods as well as fatigue testing.

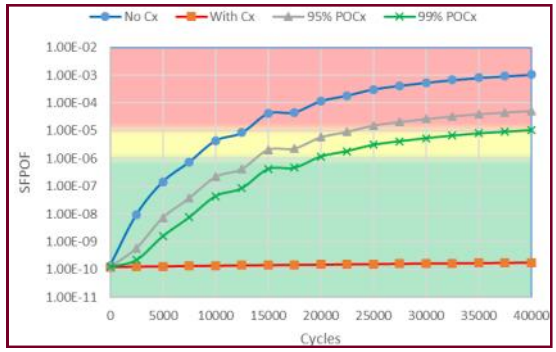
POC: Dr. Mike Hill (Hill Engineering); mrhill@hill-engineering.com

Subcommittee Spot

Risk Analysis

The goal of the risk analysis and Uncertainty Quantification (UQ) subcommittee has been to investigate and implement methods that enhance the overall understanding of how residual stresses affects a holistic approach to managing structure. A few possible ways to partially reach that goal include UQ and sensitivity analyses, where we identify the most significant variables in the ERSI process and determine how can we maximize/minimize the benefits/damages of these variables.

Several presentations of current activities were given at this year's meeting—a brief summary of each is provided below.



1. Probability of Cold Expansion (POCx) Variable (Laura Hunt, SwRI)

The A-10 ASIP office has expressed interest in how the cold expansion of holes could be incorporated into a PROF-type risk analysis. It was suggested that a Probability of Cold Expansion (POCx) variable could function similarly to the Probability of Inspection (POI) variable that is currently in PROF. POCx is a singular value that represents the probability that a hole was cold-worked "correctly", where the definition of "correctly" must still be defined.

The results from the ERSI Fatigue Crack Growth Analysis round-robin were used as an input for the Cx hole case analyzed. Residual stresses were removed from the AFGROW input to create results for a theoretical non-Cx hole case, then separate PROF analyses were run for the Cx and non-Cx cases. The Single Flight Probability of Failure (SFPOF) results for both analyses were imported into Excel, incorporating both the 95% and 99% POCx. See SFPOF results in figure above.

NOTE POCx is a simple knockdown factor to incorporate residual stresses, but has the danger of becoming a "thumb-in-the-air" type variable. UQ is still required to actually quantify this variable.

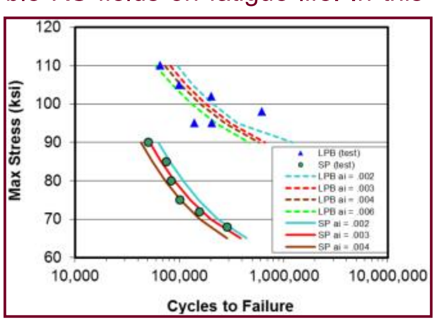
POC: Ms. Laura Hunt (SwRI); ldomyancic@swri.org

2. Some Observations on the Significance of Residual Stress Variability on Fatigue Crack Growth Life (Dr. Craig McClung, SwRI)

Two anecdotal examples are given below on the significance of variability in residual stress on fatigue crack growth lifetime.

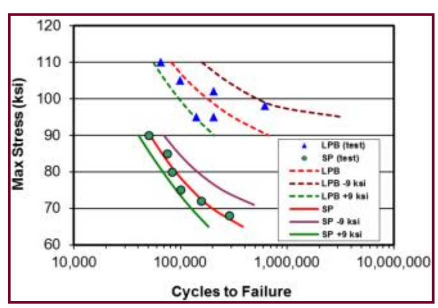
Example 1: Relaxed surface residual stress field created by surface enhancement

Surface enhancement methods such as shot peening (SP) or low plasticity burnishing (LPB) can introduce significant near-surface compressive RS fields. FCG analysis can be used to predict the influence of the resulting stable RS fields on fatigue life. In this example, alpha-beta Ti-6Al-4V laboratory coupons were subjected to SP or LPB and then thermally exposed (425°C/10 hrs) before RS profiles were measured.



These RS profiles were then inserted into a univariant weight function surface crack stress intensity factor solution. Hypothesizing that the surface enhancement could have introduced microscopic damage that would initiate fatigue cracks quickly, FCG analyses with small initial crack sizes were used to calculate total fatigue life. A simple El Haddad model was used to describe small-crack growth rate behavior.

Results indicate that variations in the assumed initial crack size had relatively little impact on calculated life (compare large scatter in fatigue lifetimes in figure above). Small shifts (±9 ksi) in the RS profiles, hypothetically arising from process variability or measurement uncertainty, had a much larger impact on calculated life and were consistent with limited data for life scatter—see figure at right. [All data courtesy of Lambda Technologies]

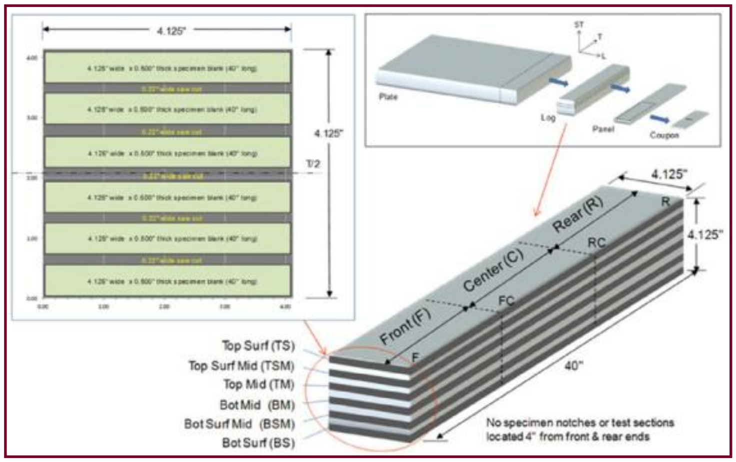


Risk Analysis (cont'd)

Subcommittee Spot

Example 2: Bulk residual stress field created by heat treating

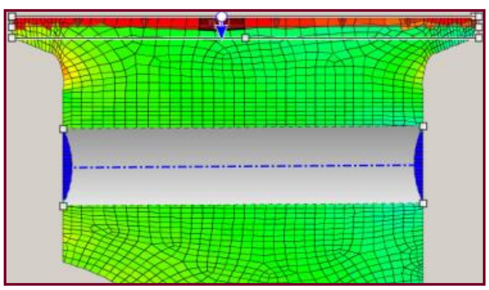
A 7085-T74 billet was cut into many 'logs' that were quenched and aged individually to intentionally leave significant residual stress. Coupon blanks extracted from three longitudinal positions and six transverse positions (total of eighteen unique positions) within each log—see right image.



The approach consisted of taking slitting RS measurements (shown below), inputting into an FEA, and getting a predicted DF residual stress. A Principal Components Analysis was then performed, which allowed for the creation of probabilistic RS Models, which were used to do FCG predictions/comparisons.

Two sets of experiments were performed—one set with an initial crack in the region of tensile residual stress, and the other set with an initial crack in the region of compressive residual stress.

In these tests, the RS had a significant impact on the predicted life, and predictions ignoring RS tended to be highly conservative or highly non-conservative. Predictions (32 tests) including mean value RS were generally accurate (±2x) with a conservative bias for constant amplitude loading, and accurate (±2x) with no bias for spectrum loading. Scatter in tensile RS generally had a very small effect, while scatter in compressive RS generally had a very large effect. [All data from MAI BA-11 project]

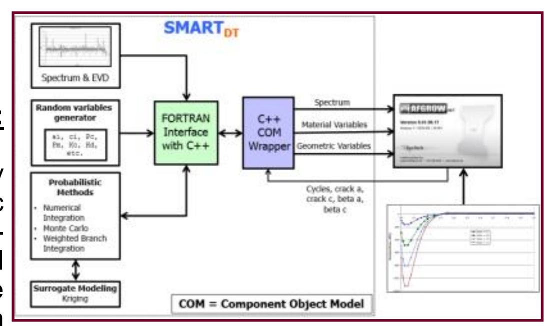


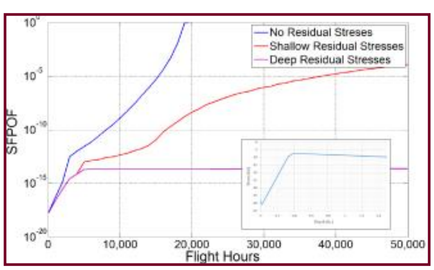
So what is a possible path forward for ERSI regarding RS variability on FCG life? One approach would be to implement the use of DARWIN probabilistic damage tolerance software, or a similar tool used in conjunction with statistics, that could augment the development of an engineering tool that can be applied by sustainment engineers. A tool which would allow for the development of quantitative characterization of uncertainty in RS, informed by RS models and RS measurements, utilizing univariant & bivariant weight function stress intensity factor solutions to model effect of RS on crack driving force and can perform probabilistic analysis of (uncertain) RS effects on FCG life and fracture risk. An image from a DARWIN analysis is shown in left figure. In short, a more rigorous probabilistic treatment of RS uncertainty and its effect on fracture risk appears warranted.

POC: Dr. Craig McClung (SwRI); craig.mcclung@swri.org

3. Residual Stress Sensitivity Analysis in Probabilistic DTA: Dr. Juan Ocampo, St. Mary's University

The SmartDT residual stress modeling software has the capability to read experimental/simulated data and find the best deterministic and probabilistic fit parameters. A handbook problem was evaluated using SmartDT for a corner crack at a center hole with residual stress. The flow diagram for how the software interfaces with the FCG software (AFGROW in this example) is shown in the figure above. The SFPOF results with no inspections for 3 cases, no residual stress, shallow residual stress, and deep residual stress are shown in left plot.



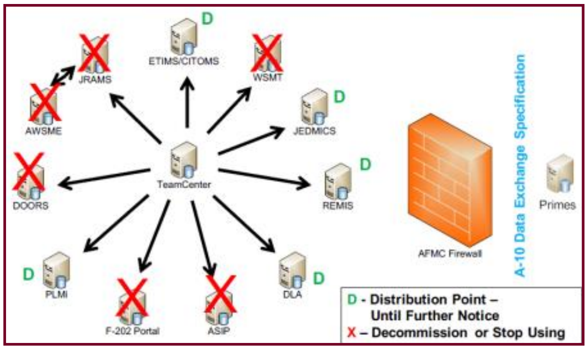


The software is very flexible and expandable to different models and scenarios. Future work includes computing sensitivities with respect to standard deviation, and further development from usage in handbook problems—however, help is needed from the ERSI community to accomplish this.

POC: Dr. Juan Ocampo (St. Mary's University); jocampo@stmarytx.edu

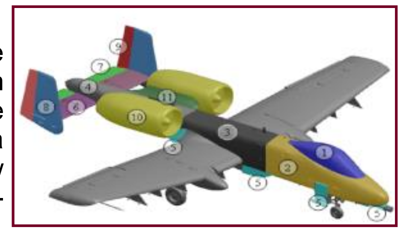
Subcommittee Spot

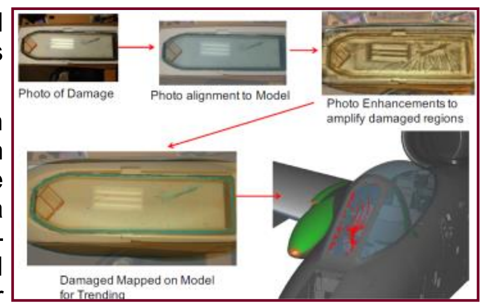
Data Management & Quality Assurance



At the 2018 ERSI Workshop, the focus of the subcommittee was on the way that the A-10 System Program Office does data management. For the A-10 Product Lifecycle Management (PLM), Teamcenter has been implemented as the single source of truth of data. The figure at left shows all the related A-10 legacy data management systems that are slowly being decommissioned/stopped to improve the process.

The A-10 has also been moving to a 3D Model Based Definition (MBD) for legacy and new assets. In this environment, data is managed under part number effectivity and uses defined critical inspection locations for data management — see these numbered defined regions in the top figure below. The interaction tool that A-10 is using for visual information communication for PLM is called NLign. NLign utilizes quick data access, live links to controlled Teamcenter documents, and live charts to quickly communicate data and feed analyses. One extremely beneficial feature of NLign is the ability of the user to map damage on a part to the model just using photos. This flow is shown in the lower figure at right.





For A-10 ASIP Quality Assurance, the focus has been data capture at the point of maintenance. For example, the A-10 Scheduled Structural Inspection (SSI) program historically takes 7-9 months from the asset induction date before Engineering sees SSI data. Even at that point, the quality of data is low and not easily usable—see the stack of log books in the image below left — and requires an engineering technician to manually input the information into a database. This system of quality assurance provides no ability for engineering to address data issues while the asset is still open and accessible. By the time the maintenance data is received, the asset is usually back on an aircraft and ready for service.

A 3D framework for quick and accurate digital inspection input is much more efficient. In August 2016, A-10 performed a NLign data collection test on the shop floor. The data capture trendable was customized for the maintainer to input data based on serial number component type, and a quick 'at a glance' reporting tool was incorporated. This allowed supervisors to stay informed of progress and helps keep the NDI technician and mechanic in sync for remaining work. For an Outer Wing Panel case in 2016, it took just 3 weeks to complete with 100% data accuracy. Data was available to engineers ~ 800% faster. For a Center Wing Panel case in 2017, it took 2.5 months to complete, again with 100% data accuracy. Data was available to engineers ~ 500% faster. In 2018, full implementation of NLign on shop floor began.

Lastly, the ERSI community should be aware of the USAF Rapid Innovation Fund (RIF) titled "Maintenance Data Spatial Positioning (DSP) System" that is currently in source selection. If awarded, this effort will provide a huge benefit to the ERSI Data Management and QA subcommittee. See description from the BAA below.

Description: Seeking the development of a maintenance DSP technology to provide real-time location feedback to maintainers, capture any maintenance tool data output, and communicate that data for condition-based aircraft management. Venders should propose and develop the methodology, technology, and hardware for incorporating the DSP system with existing maintenance non-destruction inspection (NDI) tools and cold expansion tools. Leveraging the NLign system from previous RIF efforts, the data positioning system will have the option to utilize predefined maintenance locations and provide feedback to the maintainer for location compliance. Any data output from maintenance tools should be captured with spatial coordinates and communicated to the NLign system for analysis. This tool is intended for depot or field use and to be quickly adaptable for all airframes. This effort will enhance maintenance data quality for all platforms and reduce the risk of misslocating or missing critical maintenance operations. Also, this tool will provide the missing verification and high-fidelity data needed in CBM+ to reduce serious risk concerns that have hindered the ability to apply 'game changing' fleet management strategies such as residual stress benefits.

POC: Mr. Hazen Sedgwick (USAF A-10 ASIP); Hazen.Sedgwick@us.af.mil

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 ERSI@swri.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 subcommittee chair.

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

Announcements

- **Recent and Upcoming ERSI-related events:**
  - ASTM E08 Committee Week, Nov. 5-8, 2018
    - The New Task Group E08.04.06 on Residual Stress in Structural Design and Sustainment, chaired by Dr. TJ Spradlin, met together with many ERSI individuals participating
  - ASIP Conference 2018, November 26-29, 2018
  - ASTM E08 Committee Week, May 13-15, 2019
  - 19th International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics (42nd National Symposium on Fatigue and Fracture Mechanics), May 17, 2019
  - ERSI Workshop 2019: TBD

- **ERSI Subcommittee 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 subcommittees, please refer them to contact the ERSI Organizers or applicable subcommittee chair.
  - REMINDER: While we do encourage people to join in the different subcommittees freely, attendance at the ERSI Workshop is by invitation only from the ERSI Organizers. If you would like to attend the 2019 ERSI Workshop, please contact the ERSI Organizers and we will review your request. Active participation and involvement in at least one of the subcommittees is one of the metrics used to assess Workshop attendance.

- **ERSI contact info:**
  - If you ever have questions, suggestions, complaints, etc., please let us know by sending an email to ERSI@swri.org. Any feedback on the ERSI workshop, subcommittee lead roles, ERSI purpose, or any other topic is always appreciated.

- **ERSI website is up and running!**
  - If you have an account, go to https://member-ersi.swri.org/ and login. If you need an account, please send an email to ERSI@swri.org and an account will be created for you. Please include your name, organization, and contact info.
  - All of the 2018 ERSI Workshop presentations are uploaded on the website for you to view.
  - For the subcommittee leads, a 'super user' role has been assigned to you that allows you to upload files directly to the website. If you have any issues, please let us know.

Who is ERSI?