2025 ERSI Workshop Welcome!

30 April 2025

Dallen L. Andrew, PhD

ERSI
ENGINEERED RESIDUAL STRESS IMPLEMENTATION

Agenda

- Around the room
- Committee
- Impact slide
- Roadmap
- EZ-SB-17-001 Rev B
- ERSI Interactions
- Discussion & Feedback

Important Stuffs

- Nametags/Poster photos
  - Also I apologize if I missed you or messed up your name
- Coffee/Candy/Cookies/Drinks
- WSU Guest wifi available
- Attendee appreciation gifts

A huge thanks to our sponsors for this year:

HILL ENGINEERING
PART WORKS
LexTech
PROTO MANUFACTURING
SwRI
FTI FATIGUE TECHNOLOGY
esrd

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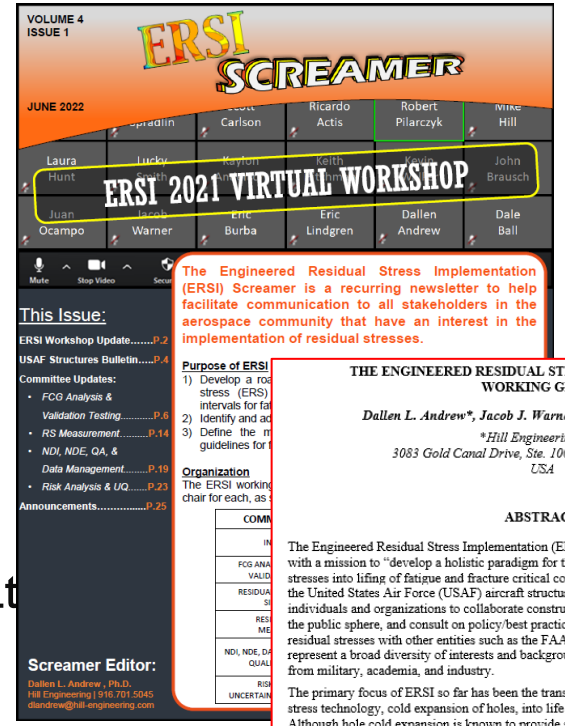
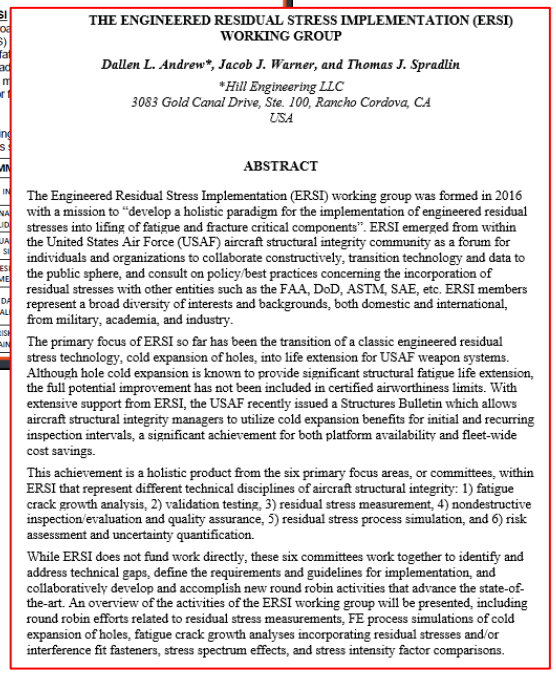
ERSI purpose: Where does ERSI add value?

- **EZ-SB-17-001**
- **Analysis and testing**
  - 2016: FCG analysis of Cx holes
  - 2020: Interference fit fasteners
  - 2021: SIF Comparison
  - 2021: Overload challenge
  - 2022: Interference fit fasteners round 2
- **Residual stress characterization**
  - 2017: 2x2 material modeling data
  - 2017: 2x2 Cx Coupons
  - 2017: Contour method inter-laboratory reproducibility uncertaint
  - 2019: 2x2 process simulation analysis
  - 2021: Texture and anisotropy sub-team
  - 2021: Bulk RS measurements in Cx geometrically large holes
  - 2022: Contour method reproducibility experiment A (CMRE-A)
- **NDI / NDE / Data management / Quality assurance**
  - xx: Cx hole blind study [POC: Dallen Andrew, Hill Engineering]





THE ENGINEERED RESIDUAL STRESS IMPLEMENTATION (ERSI) WORKING GROUP

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3083 Gold Canal Drive, Ste. 100, Rancho Cordova, CA
USA

ABSTRACT

The Engineered Residual Stress Implementation (ERSI) working group was formed in 2016 with a mission to "develop a holistic paradigm for the implementation of engineered residual stresses into lifing of fatigue and fracture critical components". ERSI emerged from within the United States Air Force (USAF) aircraft structural integrity community as a forum for individuals and organizations to collaborate constructively, transition technology and data to the public sphere, and consult on policy/best practices concerning the incorporation of residual stresses with other entities such as the FAA, DoD, ASTM, SAE, etc. ERSI members represent a broad diversity of interests and backgrounds, both domestic and international, from military, academia, and industry.

The primary focus of ERSI so far has been the transition of a classic engineered residual stress technology, cold expansion of holes, into life extension for USAF weapon systems. Although hole cold expansion is known to provide significant structural fatigue life extension, the full potential improvement has not been included in certified airworthiness limits. With extensive support from ERSI, the USAF recently issued a Structures Bulletin which allows aircraft structural integrity managers to utilize cold expansion benefits for initial and recurring inspection intervals, a significant achievement for both platform availability and fleet-wide cost savings.

This achievement is a holistic product from the six primary focus areas, or committees, within ERSI that represent different technical disciplines of aircraft structural integrity: 1) fatigue crack growth analysis, 2) validation testing, 3) residual stress measurement, 4) nondestructive inspection/evaluation and quality assurance, 5) residual stress process simulation, and 6) risk assessment and uncertainty quantification.

While ERSI does not fund work directly, these six committees work together to identify and address technical gaps, define the requirements and guidelines for implementation, and collaboratively develop and accomplish new round robin activities that advance the state-of-the-art. An overview of the activities of the ERSI working group will be presented, including round robin efforts related to residual stress measurements, FE process simulations of cold expansion of holes, fatigue crack growth analyses incorporating residual stresses and/or interference fit fasteners, stress spectrum effects, and stress intensity factor comparisons.

Around the room

- ~60 seconds
- Name
- Company
- What do you do
- Why are you here

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Around the room updates

- Round robin activities
- Opportunity for collaboration (w/in ERSI and outside)
- USAF/DoD/Industry RS related interest, use, needs

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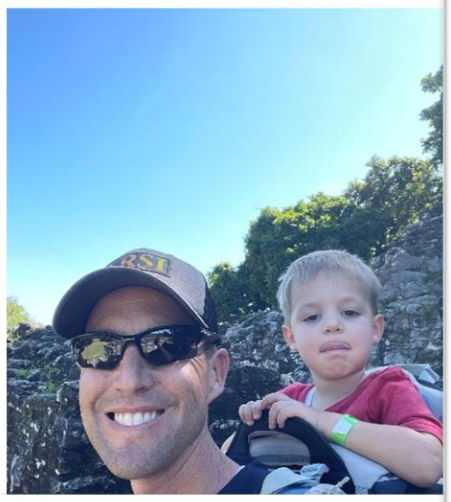
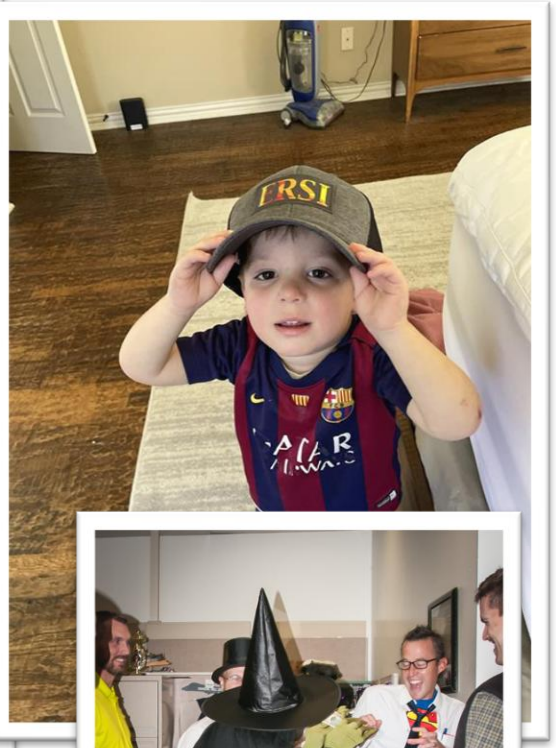
Committees

- Thoughts on committees, leads, and needs
  - Welcome [back] Dr. Carlson

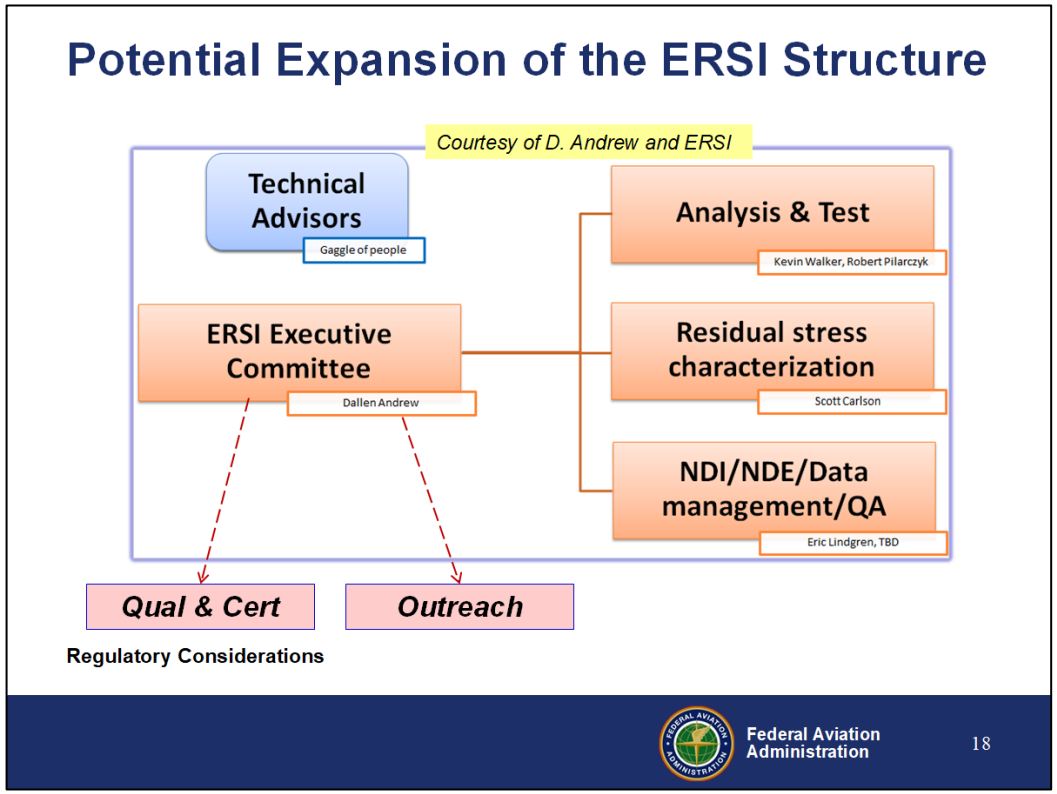




Committees

- Thoughts on committees, leads, and needs
  - How is the committee structure working for you?
    - 8 vs 3 vs 1
    - Time served, replacements
  - Regulatory considerations, Outreach

- Committee: Integrator
- Committee: Fatigue Crack Growth Analysis Methods
- Committee: Validation Testing
- Committee: Residual Stress Process Simulation
- Committee: Residual Stress Measurement
- Committee: Data Management & Quality Assurance
- Committee: Nondestructive Inspection
- Committee: Risk Analysis & Uncertainty Quantification



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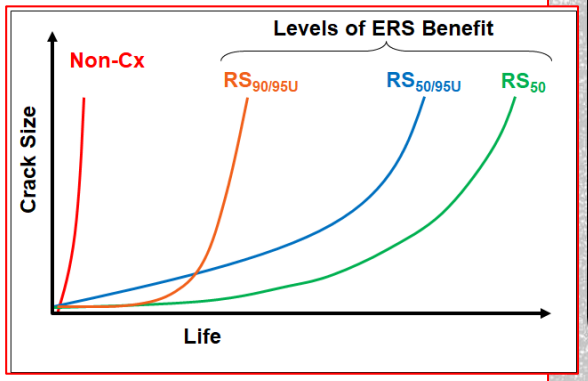
ERSI Impact

- What would 1 impact slide for ERSI look like?
  - Who's our audience?
    - Technical? Engineering manager? 3 star general?
    - *What would the [your name here]s of the world want to take to "management" to justify a RS-related [IR&D] test program?*
  - Convey issue/scope
    - Impact (recurring intervals?); example; SPO budgets;
  - Key accomplishments



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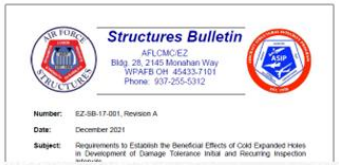
BLUF

- As the USAF inventory continues to age and fleets are operated well beyond their original design goals, sustainment costs continue to escalate.
  - The DoD annual depot maintenance costs are expected to exceed $30B in FY2024
- Engineered residual stresses provide a significant opportunity to extend the life of existing DoD platforms.
- However, it's been shown repeatedly that the ability to properly analyze, apply, and measure engineered residual stresses requires advanced knowledge to ensure appropriate application.
  - Accomplished through an extensive test and analysis program on each individual case with significant cost.
- With the increased number of assets grounded for maintenance, the ability to develop engineered residual stress techniques to extend airframes and lengthen intervals between inspections is essential technology.

Countries Involved: **5**
US Govt Organizations: **4**
USAF ASIP Managers: **10**
National Laboratory: **2**
Universities: **6**
OEMs: **3**
Industry Partners: **34**
ERSI Participants Total: 152

ORIGIN & FOCUS

- The Engineered Residual Stress Implementation (ERSI) working group is a grassroots organization that emerged from within the USAF ASIP community
- Initially formed to identify and address observed technical gaps, define the requirements and guidelines for implementation, and collaboratively develop and accomplish new round robin activities that advance the state-of-the-art concerning the incorporation of residual stresses.
- ERSI consists of three primary focus areas that represent the technical disciplines of aircraft structural integrity that work together: 1) analysis and test, 2) residual stress characterization, and 3) nondestructive inspection/evaluation, quality assurance, data management.


Structures Bulletin
AFLCMC/EZ
Bldg. 28, 2145 Monahan Way
WPAFB OH 45433-7101
Phone: 937-255-5312
Number: EZ-SB-17-001, Revision A
Date: December 2021
Subject: Requirements to Establish the Beneficial Effects of Cold Expanded Holes in Development of Damage Tolerance Initial and Recurring Inspection

KEY ACCOMPLISHMENTS

- With extensive support from ERSI, the USAF recently issued a Structures Bulletin which allows aircraft structural integrity managers to utilize cold expansion benefits for initial and recurring inspection intervals, a significant achievement for both platform availability and fleet-wide cost savings.
- In addition, ERSI holds an annual workshop and issues a recurring newsletter – the ERSI Screamer - to facilitate communication across the structural integrity community

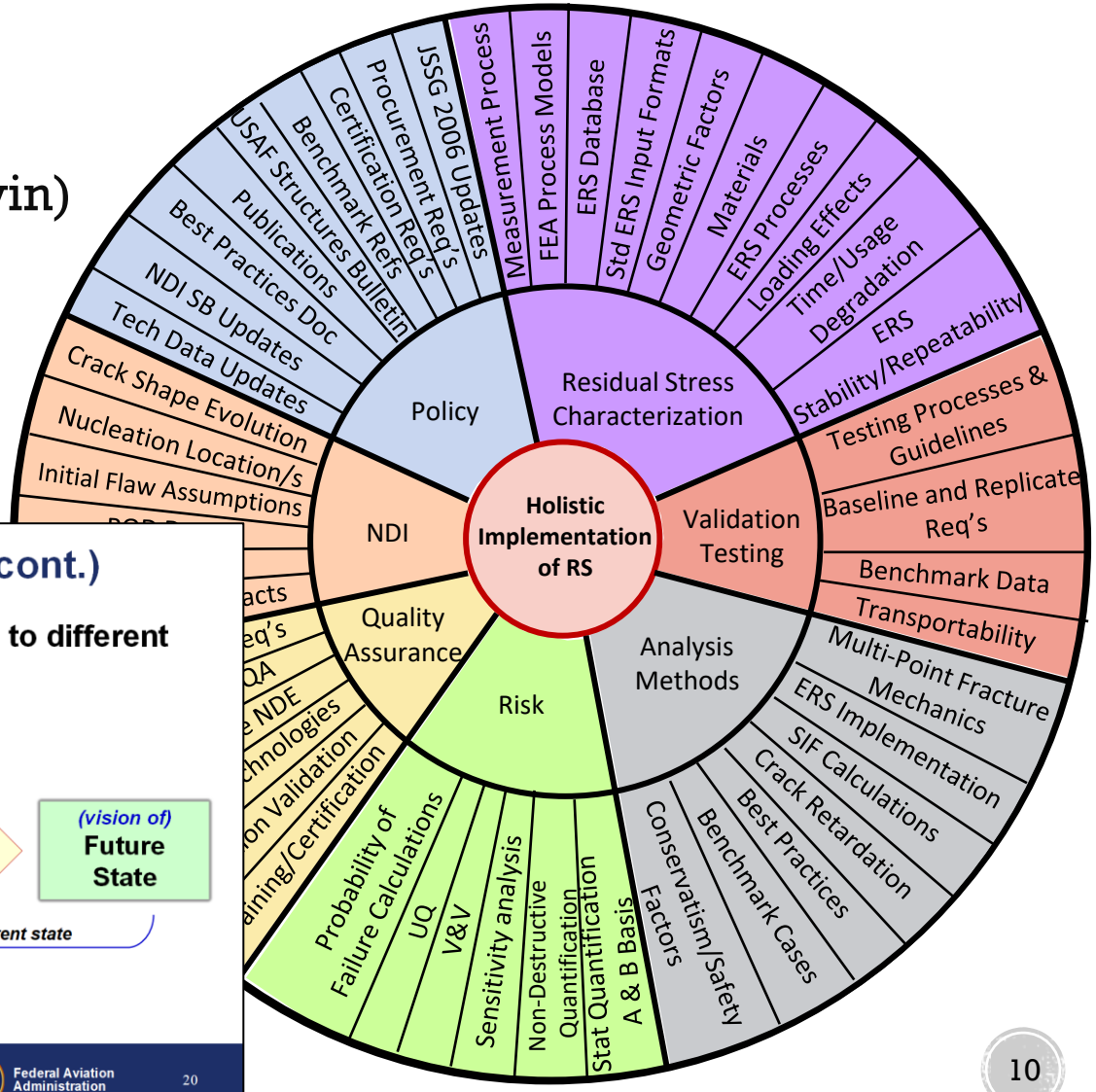
IMPACT

- ERSI represents/captures the stakeholders that are pursuing improved platform availability at less investment per insertion.
- For many USAF aircraft, fastener holes are primary driver for structural inspections, accounting for ~70-90% of fatigue critical locations
  - Cold expansion has been utilized during production and retrofit on approximately 25% to 40% of these critical fastener holes.
- Moving toward a "full credit" approach, where credit for the residual stress from Cx is included to estimate the expected benefit, could have a tremendous impact on reducing maintenance costs for USAF fleets

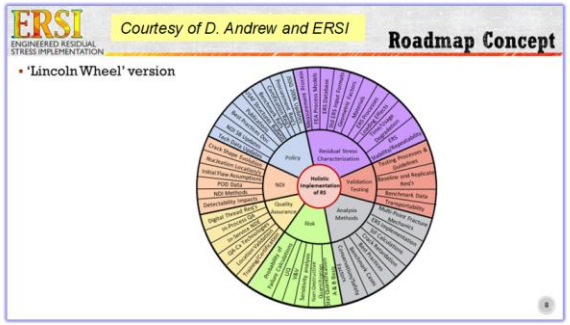
www.residualstress.org

Roadmap Concept

- 'Lincoln Wheel' version
- Need? Usage? Purpose?
  - "Needs of the customer" is not on Lincoln wheel (Kevin)



Roadmap Considerations

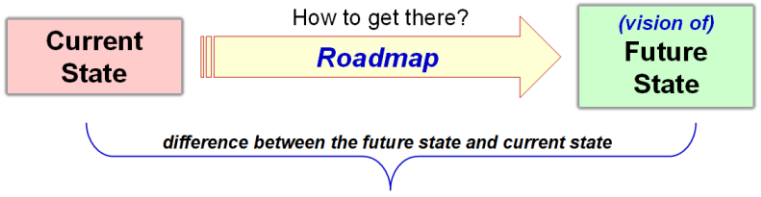


- A very thorough list of relevant categories
- However, does not provide the current status or prioritization considerations for implementation

Roadmap Considerations (cont.)

"Roadmap" means different things to different people

One interpretation →



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EZ-SB-17-001 Rev B (LAST YEAR)

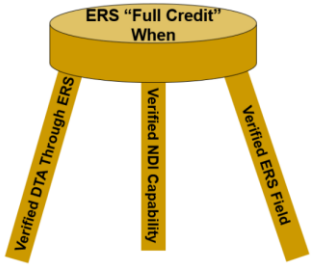
- Applications to IFF, ForceTec, ForceMate, Taper-Lok, other
- Rev B status
  - Targeting Level 3 benefit
  - Challenges
    - ~~Defining/prescribing the MPFM analysis process & associated details~~
    - ~~Defining/prescribing requirements for RS field~~
    - Verifying Cx was done & was in-spec

Benefit Levels:

Variations in the amount of benefit needed for the range of aircraft structure applications, their associated complexity, and the cost to substantiate each, has prompted the need to establish different benefit levels as follows:

Level I: Initial inspection interval benefit, using the method described in References 1 and 2 and further defined below, with no recurring inspection interval benefit.

Level II. Level I initial inspection interval benefit and limited recurring inspection interval benefit through explicit incorporation of the non-verified residual stress field in the crack growth analysis.



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FCG BENEFIT FOR CX HOLES: LEVEL 2 REQUIREMENTS (TESTING)

- Coupon testing under representative spectrum loading
  - Minimum 5 replicates of baseline and CX condition
  - More replicates required if scatter amongst replicates is greater than factor of 2
- Validation testing required for similar geometry, "similar" meaning:
  - Representative loading spectrum, max spectrum stress less than or equal to stress tested
  - e/D < 2.0 must match edge margin within 0.25, no requirement for e/D > 2
  - Diameter within ¼" for holes < ¾", > ¾" must match design geometry
  - Thickness must be within neighboring thickness range for MMPDS allowables [7]
  - Same alloy series and representative applied expansion

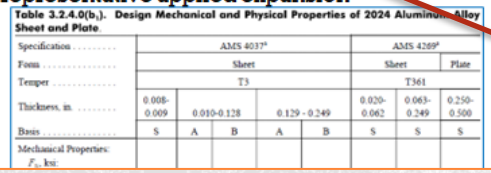
Table 3.2.4.0(b$_1$). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate.

Specification	AMS 4037[a]					AMS 4269[a]		
Form	Sheet					Sheet		Plate
Temper	T3					T361		
Thickness, in.	0.008-0.009	0.010-0.128		0.129 - 0.249		0.020-0.062	0.063-0.249	0.250-0.500
Basis	S	A	B	A	B	S	S	S
Mechanical Properties:								

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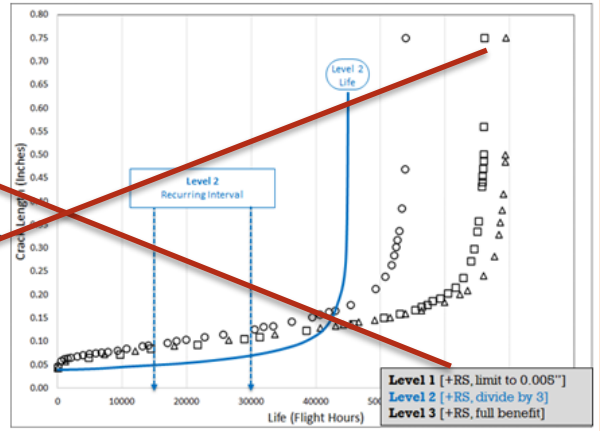
FCG BENEFIT FOR CX HOLES: LEVEL 2 REQUIREMENTS (ANALYSIS)

- Validated RS field
  - "Validated" means obtained from a direct determination method or from a model/tool that has been validated to a direct determination method
  - Same design space as testing requirements
- Analysis correlated to test
  - "Correlated" includes evaluating goodness of fit for curve shape to test data not just total life
  - Load interaction (retardation) effects are not permitted for use in a Level 2 analysis
  - Prediction must under predict the test average
  - Inspections required at predicted life **divided by 3**
- Auditable verification of proper Cx required



EZ-SB-17-001 Rev B (DRAFT)

- Requirements to Establish the Beneficial Effects of Cold Expanded Holes and Similar Life Improvement Methods in Development of Damage Tolerance Initial and Recurring Inspection Intervals
- Benefit Levels:
  - Variations in the amount of benefit needed for the range of aircraft structure applications, their associated complexity, and the cost to substantiate each, has prompted the need to establish different benefit levels as follows:
    - Level I: Initial inspection interval benefit, using the method described in References 1 and 2 and further defined below, with no recurring inspection interval benefit.
    - Level II. Level I initial inspection interval benefit and limited recurring inspection interval benefit through explicit incorporation of the residual stress field in the crack growth analysis.
    - Level III. Initial and recurring inspection interval benefits are derived from analysis correlated to the shortest benefit observed in test. **Requires on-aircraft verification of residual stress** and explicit incorporation of the residual stress field in the crack growth analysis.

3 Level III Benefit

3.1 Level III Test Requirements:

The Level III test requirements are identical to those given in Section 1.2.

3.2 Level III Test Data Acceptance Criteria:

The Level III acceptance criteria are identical to those given in Section 1.3.

3.3 Level III Analysis Requirements and Benefit Determination:

For this benefit level, the analyses described in Section 2.4 must be performed. The primary difference between a Level II and Level III is that a Level III benefit is not limited to the predicted life from Analysis 1 in Section 2.4. For Level III the maximum benefit for a recurring inspection interval is limited to the shortest cold expanded damage tolerance coupon test life and requires that all analysis predictions be less than or equal to the average of the cold expanded hole damage tolerance tests (excluding runout tests) in order to utilize any recurring interval benefit.

In addition, the following quality assurance (QA) requirements must be met in order to utilize a Level III benefit:

- Quantified and auditable verification that cold expansion was accomplished is required (e.g. – cold expanded puller load data at time of cold expansion, NDE data at a time post-cold expansion, etc.)
- The level of cold expansion (e.g. – applied or residual expansion) determined from the previous step must correlate directly with the residual stress field that is applied to the DTA and the test coupons from Section 3.1
- Quantified and auditable verification that the proper hole(s) location was cold expansion is required (e.g. – spatial position tracking of cold expansion puller at time of cold expansion, location of NDE tooling at a time post-cold expansion, photographic evidence, etc.)
- The chief engineer or cognizant engineering authority must approve the QA data capture method and recording requirements

ERSI Interactions

- ASIP Manager Update (semi-annual, ASIP and AA&S)
  - Awareness of 'problem areas'/requirements from the SPOs
- Annual briefing to Chuck
  - Part of an ASIP review?
- Plan/Location/Desire for next year
- Coordinate ERSI efforts to present at ASIP
- Outreach
- Screamer

VOLUME 5
ISSUE 1

ERSI SCREAMER

MARCH 2024

This Issue:

Screamer Editor:
Dallen L. Andrew , Ph.D.
Hill Engineering | 916.701.5045
dlandrew@hill-engineering.com

The Engineered Residual Stress Implementation (ERSI) Screamer is a recurring newsletter to help facilitate communication 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 residual stress (ERS) for calculation of initial and recurring inspection intervals for fatigue and fracture critical aerospace components.
2) Identify and address gaps in state-of-the-art.
3) Define the most effective way to document requirements and guidelines for fleet-wide implementation.

Organization
The ERSI working group is broken up into 3 major committees with a chair for each, as shown below.

COMMITTEE NAME	CHAIR(S)
EXECUTIVE COMMITEE Dr. Dallen Andrew (Hill Engineering)	
ANALYSIS & TEST	Robert Pilarczyk (Hill Engineering) Dr. Kevin Walker (QinetiQ)
RESIDUAL STRESS CHARACTERIZATION	Dr. Eric Burba (USAF AFRL) Dr. Adrian DeWald (Hill Engineering)
NDI, NDE, DATA MANAGEMENT, & QUALITY ASSURANCE	Dr. Eric Lindgren (USAF AFRL)

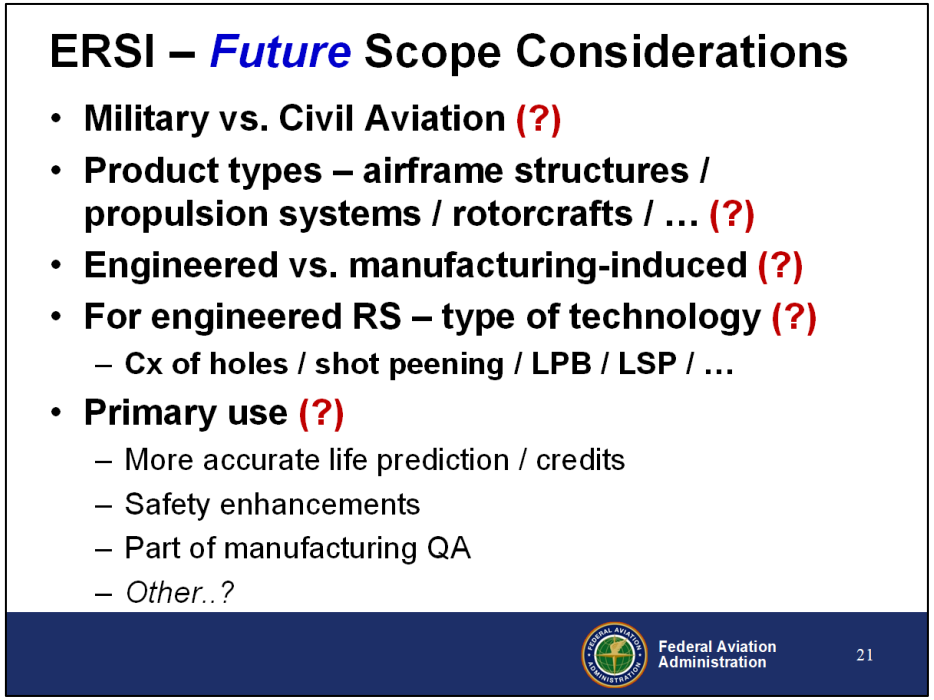
Discussion & Feedback

- Need to get regulatory people in the room
  - We're gathering the state-of-the-art but not disseminating it
- Having no load interaction in the SB is an issue
- Interest in DTA ground rules with RS?
  - Need to have 'best practices' that lays out "How ERSI is saying to do it"
  - Need a step-by-step use case of meeting the requirement of the SB
    - An ERSI report, ASM handbook, and/or ASTM STP
- Other
  - Investigating role of the sequence of precracking and Cx
  - For split mandrel process, is there NDI impacts to be considered for updates to the NDI SB?

ERSI 2024 NOTES

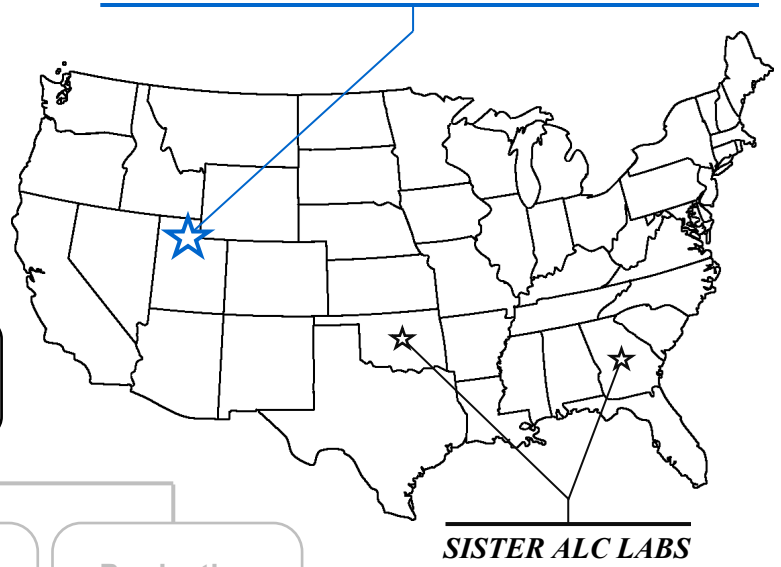
Discussion & Feedback

- What areas/topics do you want to see ERSI focus on in the near future?
- Risk analysis break-out meeting on Thursday (Mark Ryan, LM)
  - Interest, timing



809 MXSS Science & Engineering Laboratory

OGDEN AIR LOGISTICS COMPLEX



809 MXSS
Science and Engineering Laboratory

Director
Eric Billings

Technical Lead
Trevor Shoemaker

NDI PM
Ward Fong

Chemistry Flight

- Solution chemistry characterization.
- Gas Chromatography (GC) for organic characterization.
- ICP-OES for metal ion quantification.

Materials Flight

- Optical, scanning electron, NDI, and mass spec. materials characterization.
- Monotonic & cyclic loading materials testing.
- Auto. crack monitoring.
- In-house machine shop.

Adv. Mfg. (RAPID) Flight

- 3D scanners for reverse engineering efforts.
- 20+ Industrial 3D printers.
- Significant polymer and growing metal printing capabilities.

Verification Flight

- Full metrology lab.
- Touch and non-touch CMMs with +/- 0.0002” accuracy.

Metrology & Calibration Flight

Production Support Flight

Applied Research Mission:

To evaluate the suitability of **sustainment-focused** materials processing and lifing techniques for legacy and emerging structural materials.