2024 ERSI Workshop: Welcome!

2 April 2024

Dallen L. Andrew

ENGINEERED RESIDUAL STRESS IMPLEMENTATION

Agenda

1:30 PM to 2:00 PM
ERSI Welcome, Announcements, Around the room

- Purpose
- Around the room
- Committee
- Roadmap
- USAF Academy Testing
- EZ-SB-17-001 Rev A
- ERSI Interactions
- Feedback

The real important things

- Nametags
- Coffee/Candy/Cookies/Drinks
- SwRI Guest wifi available
- Breakfast tacos tomorrow
- Attendee appreciation gifts

Contributors

- Southwest Research Institute
- ESRD
- Fatigue Technology Inc.
- Hill Engineering
- LexTech
- Proto
- PartWorks

ERSI purpose

- Where & why did we start ERSI?
- Where does ERSI add value? (next slides)
  - Round robin activities
  - Opportunity for collaboration
  - Dissemination of Cx-related information/data to raise awareness & interest
- Where do we want to go now?
- What is the primary goal/target?

Vision

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

Mission Statement

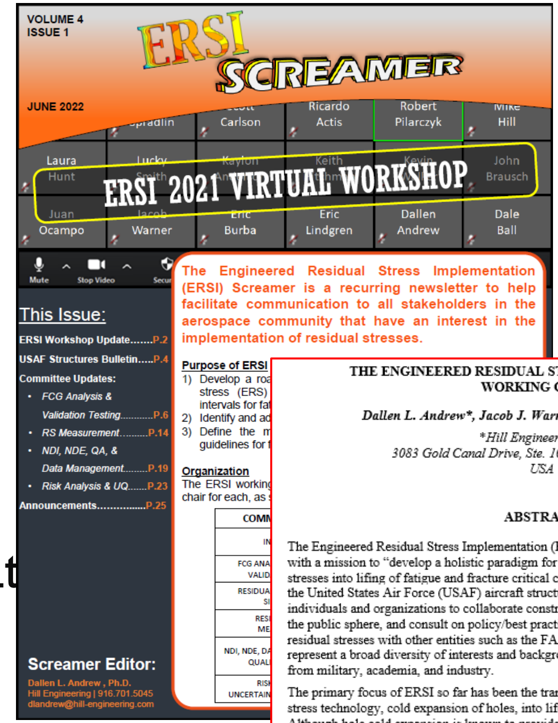
- Develop a holistic paradigm for the implementation of engineered residual stresses into lifing of fatigue and fracture critical components

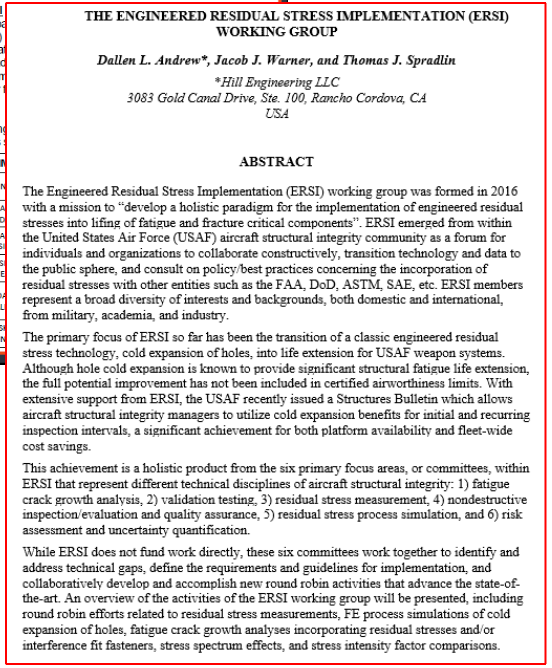
ERSI Key Objectives

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

ERSI purpose: Where does ERSI add value?

- **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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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.

Who am I?

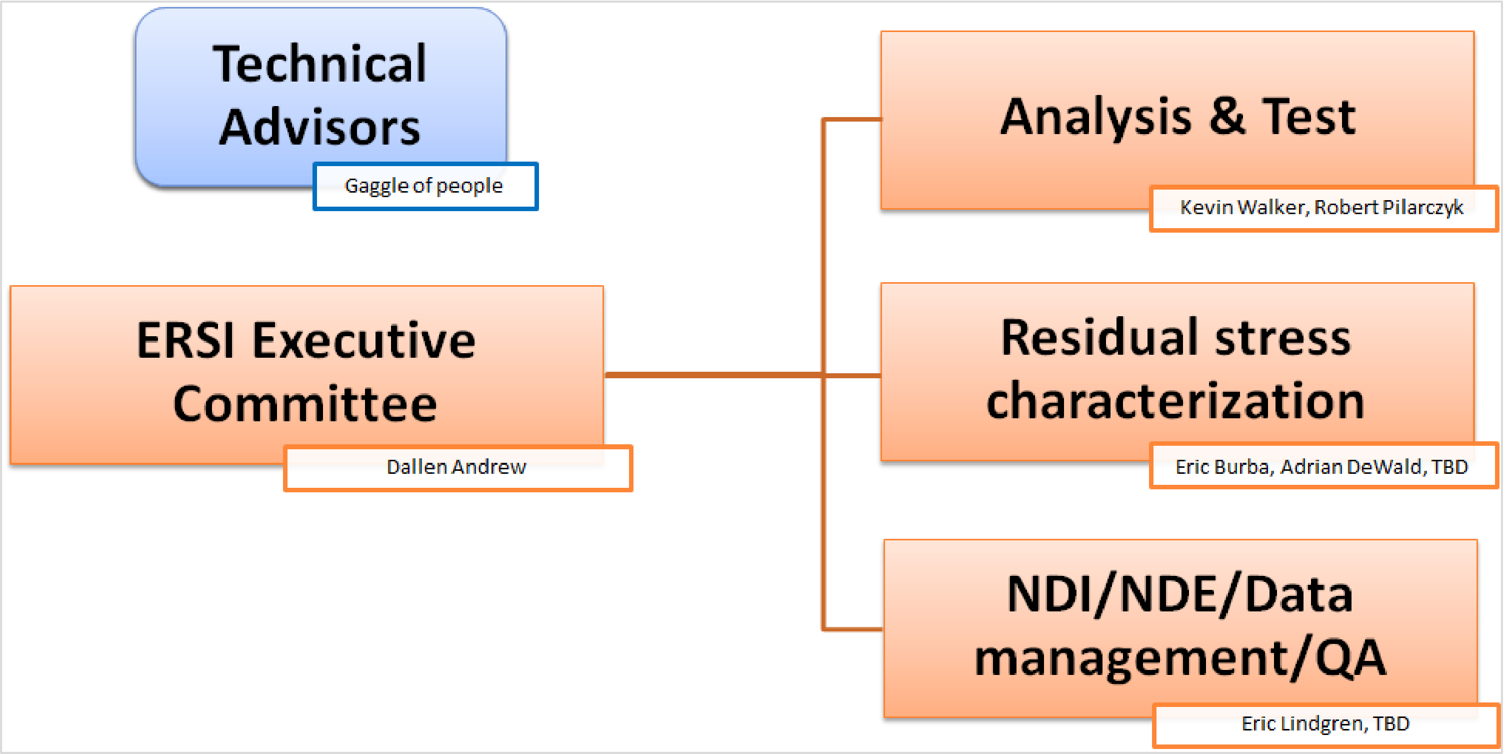
- **Original Bio**
  - Dallen started his career off working with the A-10 team under Dr. Mark Thomsen & Dr. Paul Clark, where he learned how to be both personable and silver tongued. His love of ridiculous belt buckles grew strong and pulled him to Texas where he worked for Southwest Research Institute for 5 years where he spent his free time finding ways to break the USAF cybersecurity policies, among other things. To be closer to family his wife and 4 children moved back to Utah accepting a job with Hill Engineering where he has spent the last 5 years using his impeccable helping skills to help.
- **Work**
  - USAF A-10 ASIP, Hill AFB, Utah (2009-2014)
  - SwRI, San Antonio, Texas (2014-2019)
  - Hill Engineering, Utah (2019-current)
- **School**
  - BS, Utah State University (2009)
  - MS, University of Utah (2011)
  - PhD, University of Texas at San Antonio (2020)

Who are you?

- (30-60 seconds)
- Name
- Company
- What do you do
- Why are you here

Committees

- How is the new committee structure working for you?
- Thoughts on committee leads and needs



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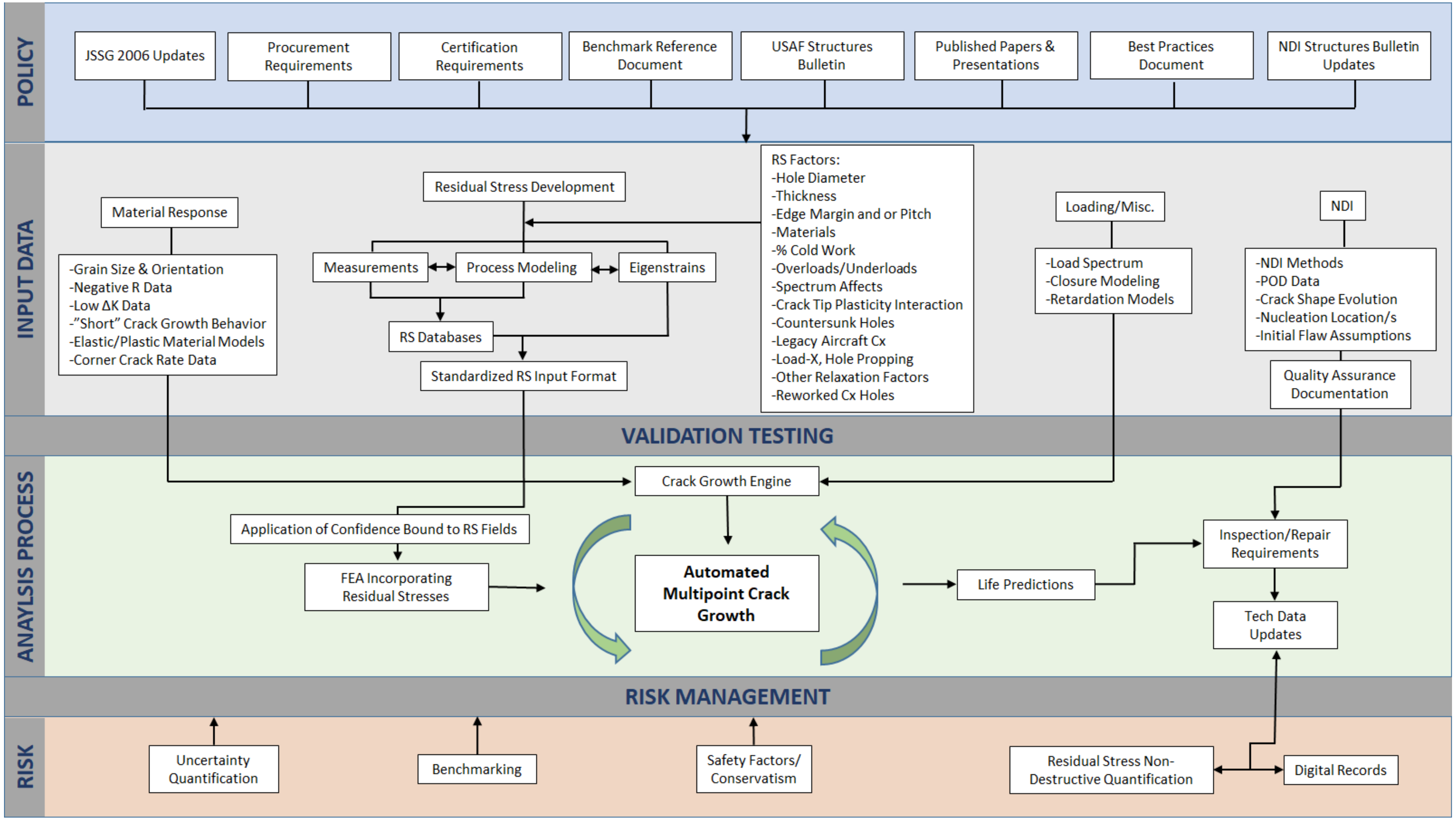
Roadmap Concept

- Flowchart version



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Roadmap Concept

- Task version

	Focus Area
1	Multipoint Crack Growth
2	Analysis Best Practices & Case Study Document
3	RS Input Format
4	Benchmarking RS Inputs
5	Hole Diameter Influence on RS
6	Thickness Influence on RS
7	Edge Margin Influence on RS
8	Fastener Pitch Influence on RS
9	Material Difference Influence on RS
10	Overloads/Underloads Influence on RS
11	Spectrum Loading Influence on RS
12	Crack Tip Plasticity Interaction w/ RS
13	Countersunk Hole RS
14	Legacy vs New CX RS - Relaxation/Redistribution
15	Load Transfer Influence on RS
16	Reworked CX Holes
17	Retardation Modeling
18	Crack Closure

Multi-Point Fracture Mechanics

Overview

Focus Item #	1	Multi-Point Fracture Mechanics (MPFM) has evolved in recent years with USAF organic and COTS options available. In recent applications, the capability has demonstrated improved analysis correlation to test as well as the ability to replicate unique crack shape evolution. For analyses incorporating residual stress, multipoint crack growth is essential to accurately predict the behavior and is central to the analytical toolbox for CX holes.
Focal	Robert Pilarczyk	
Maturity Level	TRL 3	

Constraints/Roadblocks	Threshold Criteria	Objective Criteria
	Complete benchmark problems and demonstrate MPFM relative to handbook solutions and test data. Ensure MPFM tools can facilitate implementation of RS. KPPs - correlated crack shape evolution, incorporate RS	Mature MPFC capability will multiple+ demonstration cases. Consistent results across available MPFM tools.

Questions to Resolve

Area	Focal/Contract	ECD	Current Status
1) Should we develop a best practices document for MPFM analysis?	Robert Pilarczyk, Josh Hodges	9/1/2017	Not Started
2) How do we facilitate greater utilization of MPFM to take on challenging geometric, loading, RS fatigue problems?			

Action Items

Item	Focal/Contract	ECD	Current Status
1) Val/Ver MPFM capability with multiple tools. Are results consistent with handbook solutions, test data, etc.	Possible new AFRL effort	12/1/2017	Not Funded
2) Multiple weapon system specific demonstrations comparing to fleet and/or test data. (Not necessarily RS focused)	Possible new AFRL effort	12/1/2018	Not Funded
3) Identify 3-5 benchmark RS problems to exercise current capability. Utilized different analysis tools. Round-Robin - AP/ES, NRC, A-10/T-38, H	TBD		
4) Need to review crack front and K smoothing to determine recommended best practices			

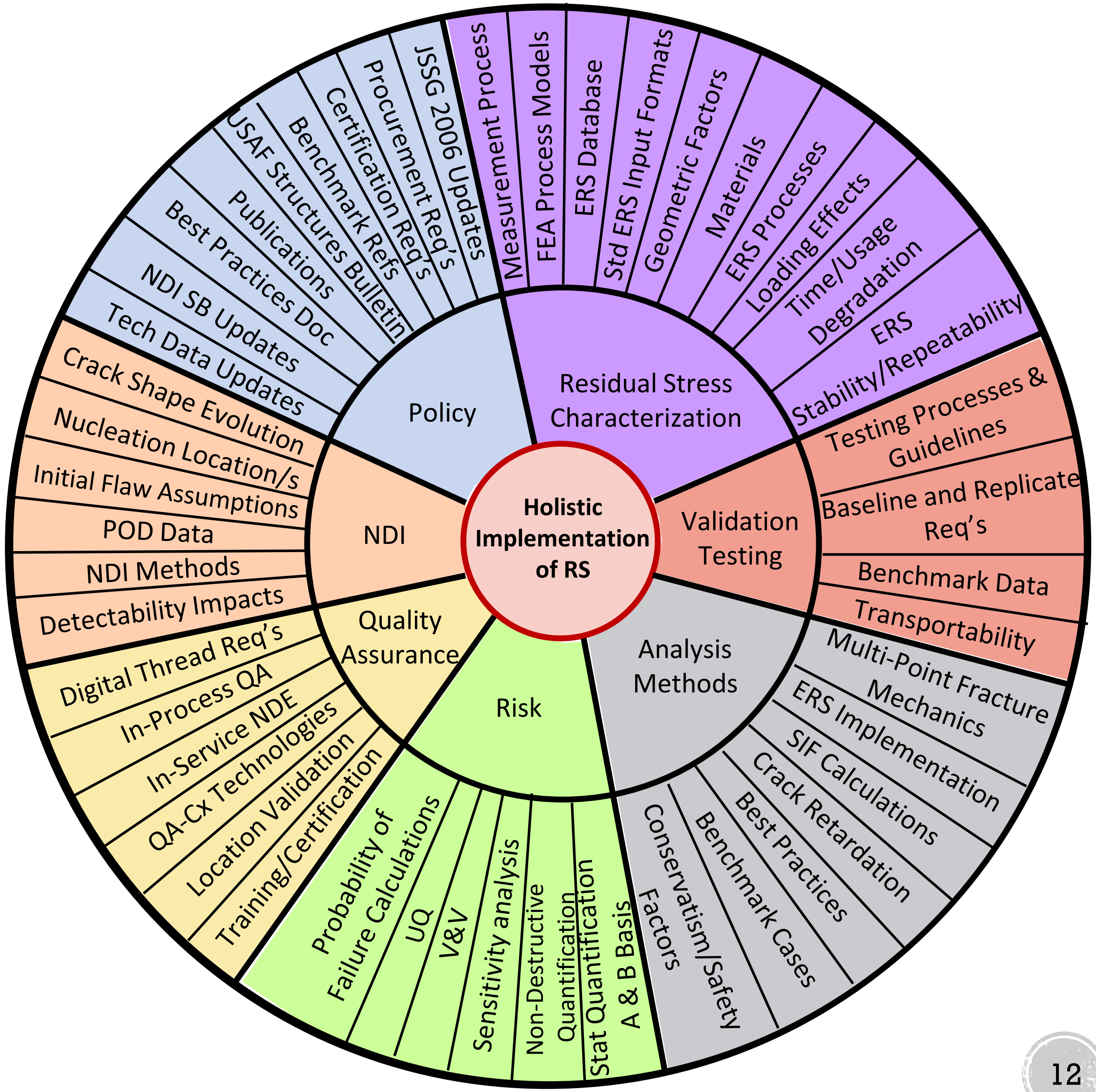
Timeline

2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

Markers on timeline: 4 (between 2015 and 2016), 7 (between 2018 and 2019)

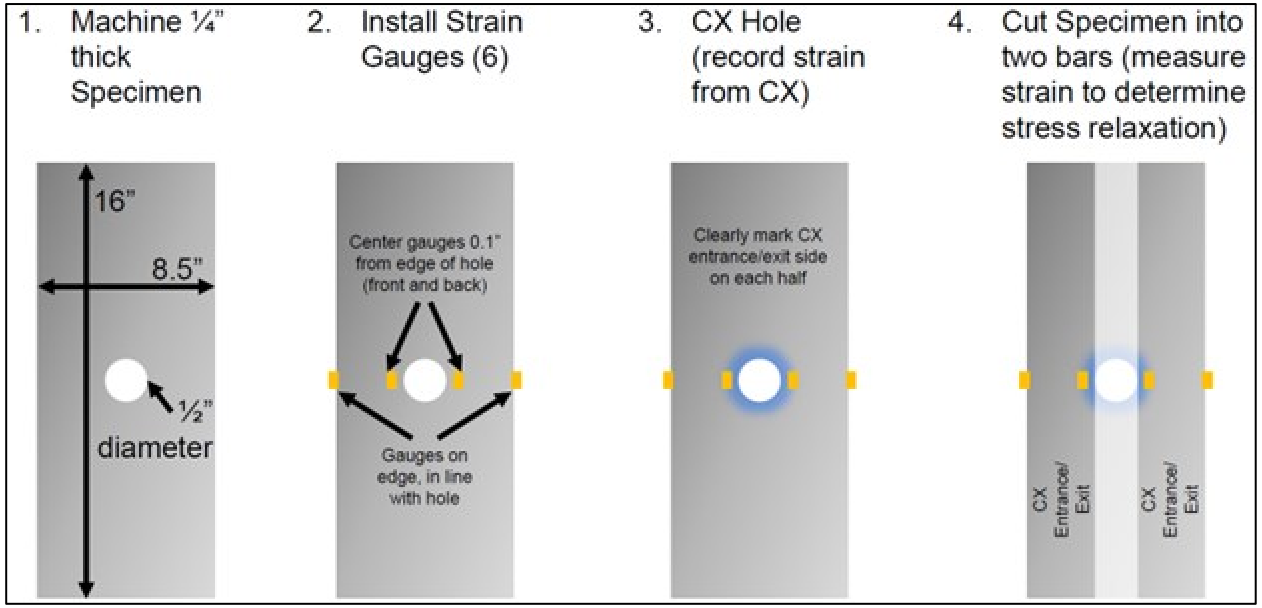
Roadmap Concept

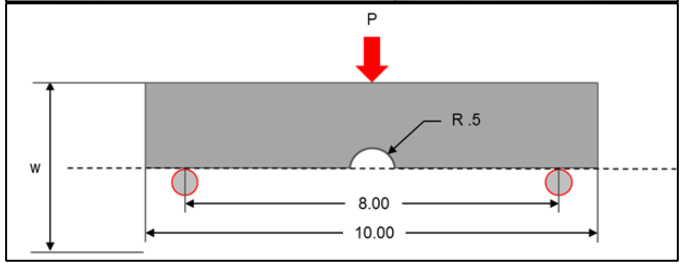
- 'Lincoln Wheel' version
  - Adding references for different focus areas
  - Highlighting where we are doing well, not so well
  - Realizing duplicate or dependent efforts
  - Gap for the focus area 'Policy'



USAF Academy Testing

- Reminder
- Previous examples
  - Kt-free Cx samples
  - GL coupons





- We do have a cadet looking for a good CAStLE project for next Fall. If anything comes to mind during the meeting, I'll be happy to discuss.

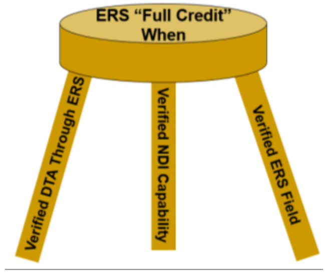
- Applications to IFF, ForceTec, ForceMate, Taper-Lok, other
- Rev B status
  - Targeting Level 2 benefit
  - Challenges
    - Defining/prescribing the MPFM analysis process & associated details
    - Defining/prescribing requirements for RS field
    - Verifying Cx was done & was in-spec

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(b₁). 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:								
F_{tu}, ksi:								

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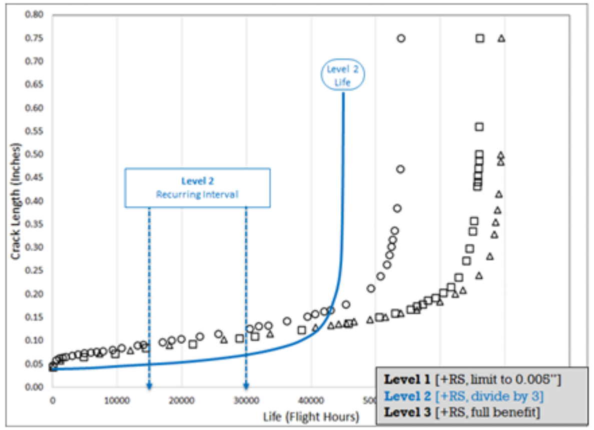
FCG BENEFIT FOR CX HOLES: LEVEL 2 REQUIREMENTS (ANALYSIS)

- 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



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ERSI Interactions

- ASIP Manager Update (semi-annual, ASIP and AA&S)
- Annual briefing to Chuck
  - Part of an ASIP review?
- Location for next year
  - Do we know if we want to plan on one?
- Review and approve all outward facing communications and publications (Like journal papers, reports)
- Coordinate ERSI-related efforts to present at ASIP, AA&S each year (could even take a session)
- Feedback on Screamer
- Feedback on website
  - ERSI committee page
- Do we need a 'chair' for communications

VOLUME 5
ISSUE 1

ERSI SCREAMER

MARCH 2024

This Issue:

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)

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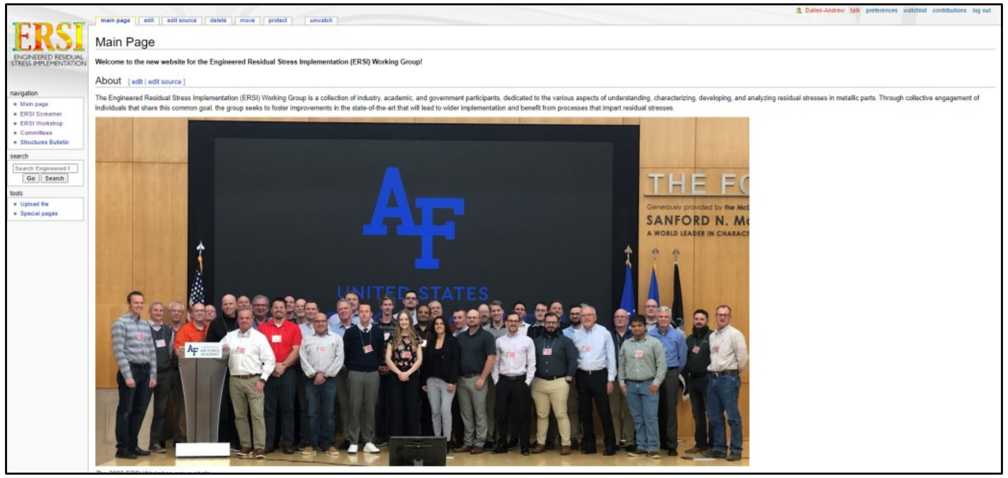

Feedback

- **Questions to help facilitate some discussions at the workshop**
  - Why are you attending the ERSI workshop and/or what do you hope to get from it?
  - How does ERSI add value to your area(s) of interest (or if it doesn't)?
  - What areas/topics do you want to see ERSI focus on in the near future?
  - What do you see the value of ERSI being going forward?

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Dinner options

- **El Chaparral**
- **The County Line**
- **Many, many, MANY more**