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**HILL
ENGINEERING**

Predict. Test. Perform.



Update on NDE for Cold Working Verification and Validation

30 April 2025

SBIR Data rights

Contract number: FA8649-24-P-0535
Contractor name: Hill Engineering, LLC
Contractor address: 3083 Gold Canal Drive, Suite 100
Rancho Cordova, CA 95670
Expiration of SBIR data rights period: 4 March 2044
In accordance with DFARS 252.227-7018

Agenda

Background

Program Overview

NDE Methods

- Screening
- Evaluation
- LFEC in-hole

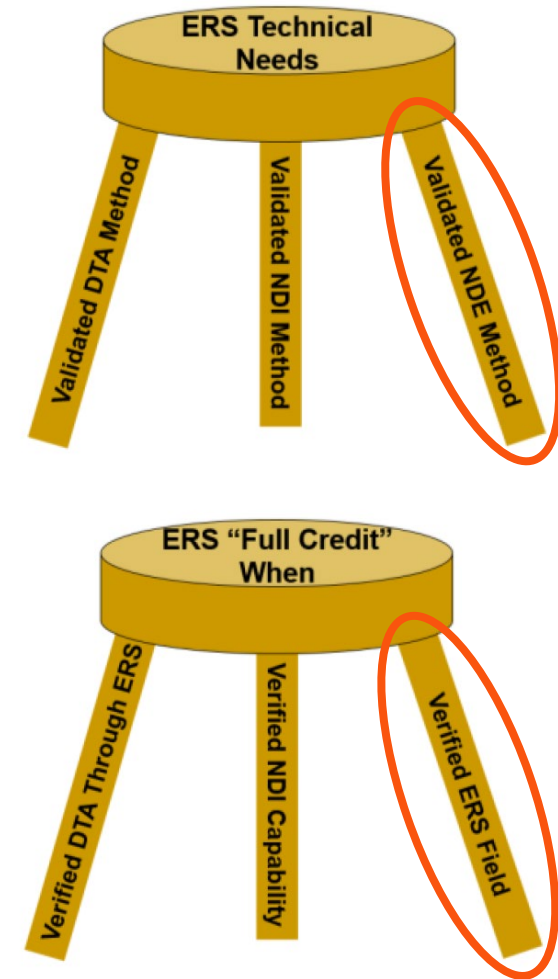
NDE Results

UT Demonstrations

Background

Significance of Problem

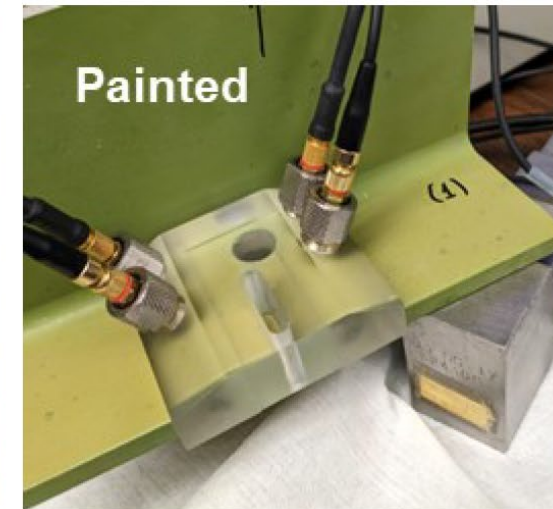
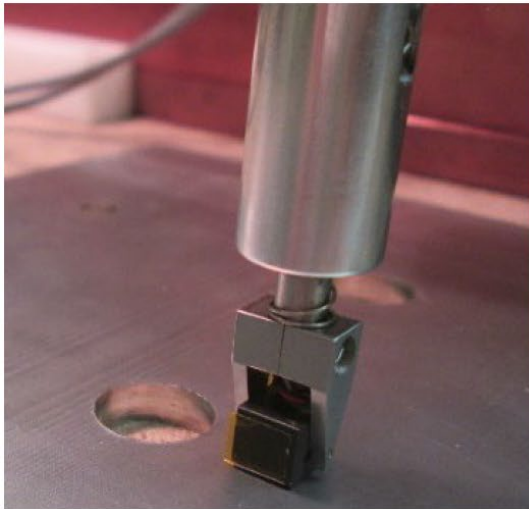
- Extensive experience applying hole cold expansion (Cx) to extend fatigue life and inspection intervals
- Critical fastener holes are the primary driver for structural inspections
 - ~70% to 90% of the fatigue critical locations on the airframe, whereas 25% to 40% are Cx'd
- Current “partial credit” benefit is due to perceived risk of missed or incorrectly Cx'd holes
 - Quality assurance tools to ensure the correct processing occurred at the correct locations are necessary to reach “full credit”
- Implementing a “full-credit” approach has a potential for tremendous impact on reducing maintenance costs for most USAF, other military, and commercial platforms as Cx has been applied widely to all types of aircraft (tactical, transport, and surveillance)
- Development of NDE technologies for Cx holes will play a critical role achieving “full credit”



AFRL Core Funded Program

AFRL Core Funded Program

- Developed & optimized prototype NDE techniques for QA of Cx residual stress
- Identified and evaluated key confounding factors
- Focused on straight shank holes, 2024 and 7075 aluminum alloys
- Down-selected to three NDE technologies
 - ET surface scan probe, LFEC in-hole probe, Longitudinal critically refracted (LCR) UT probe
- Program completion March 2023



Current SBIR Program

Leveraging results from the AFRL core funded effort, this program will mature, expand, and implement NDE technologies to meet the quality assurance needs for Cx fastener holes

Key Objectives

- Mature NDE technologies developed on previous program
- Expand NDE technology applications to include countersunk and filled holes
- Optimize NDE technologies based on program testing
- Characterize reliability of NDE technologies
- Refine system components to support fielding of NDE technologies
- Validate and demonstration NDE technologies in relevant environment (TRL = 6)

Program Tasks

- ✓ Task 1: Program Kickoff
- ✓ Task 2: NDE Technology Assessment and Requirements Definition
- ✓ Task 3: NDE Technology Optimization
- ✓ Task 4: NDE Technology Evaluation
- Task 5: NDE Technology Implementation
- Task 6: NDE Technology Demonstration
- Task 7: Meetings and Reporting

Schedule

Period of Performance

- 3/6/24 – 12/4/25

Description	2024												2025											
	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec		
Task 1																								
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Meetings and reporting																						X		

Current Date

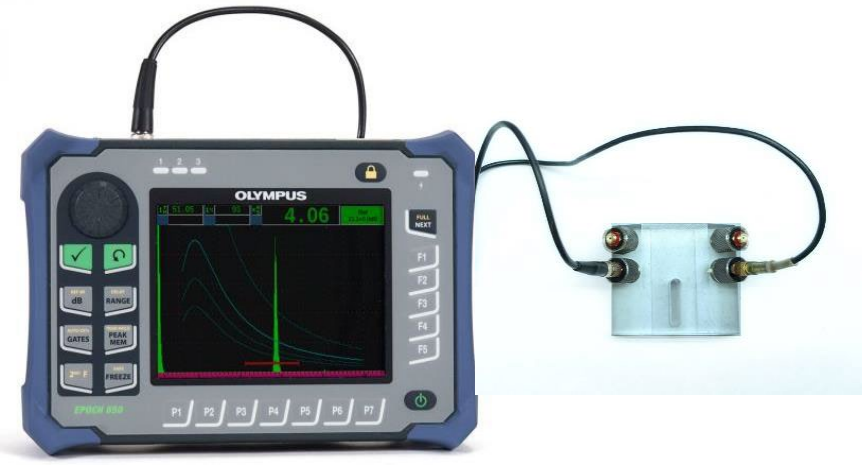
UT Surface Scan

Utilizes longitudinal critically refracted (LCR) ultrasound wave to measure the amount of hoop stress around a hole

- Cross correlation of LCR waves provide a time-of-flight shift (dToF) when RS is present
- Scanning multiple points moving in radially self-normalizes the measurement
- Screening mode utilizes 2 points (baseline and max stress)
- Evaluation mode collects points along the entire radial path provide more detailed measurement

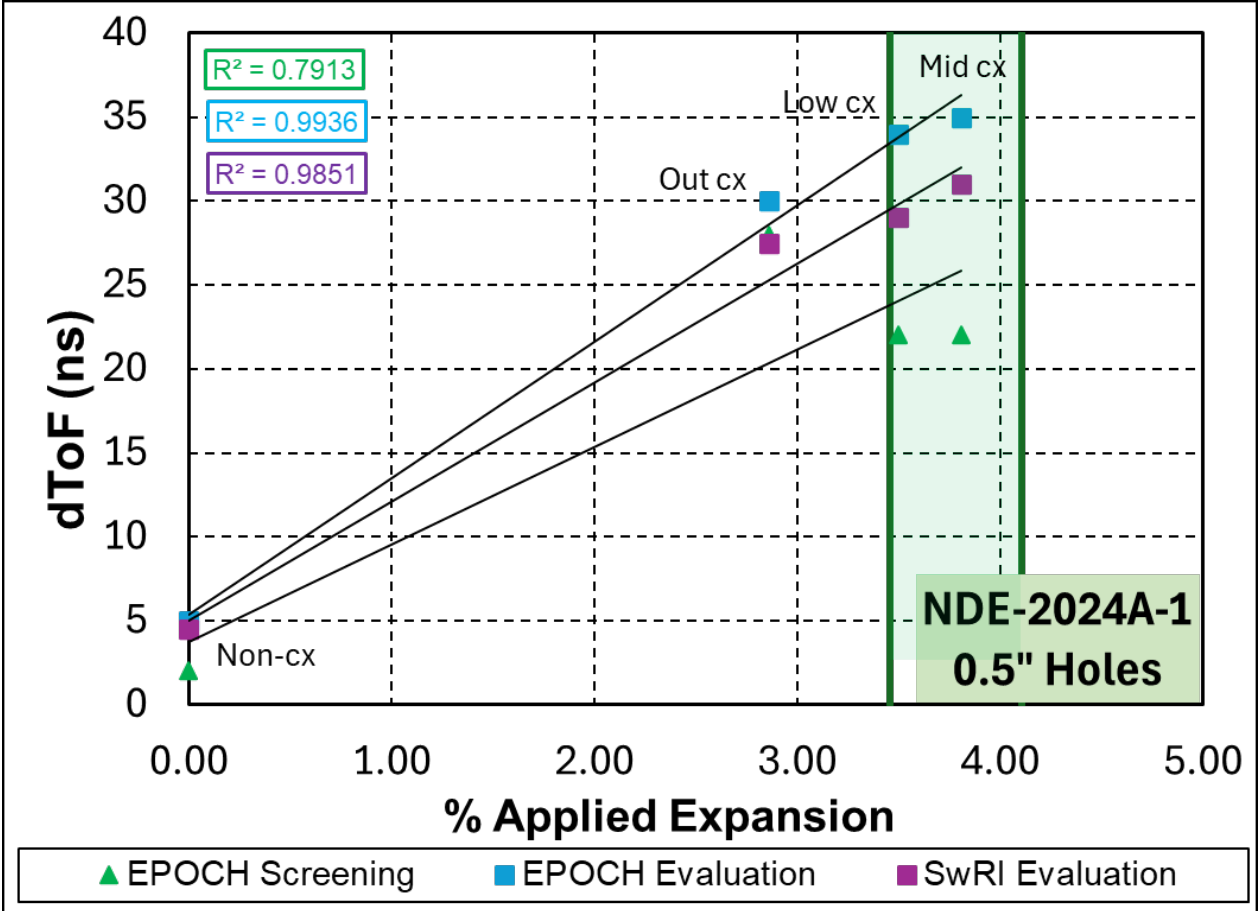
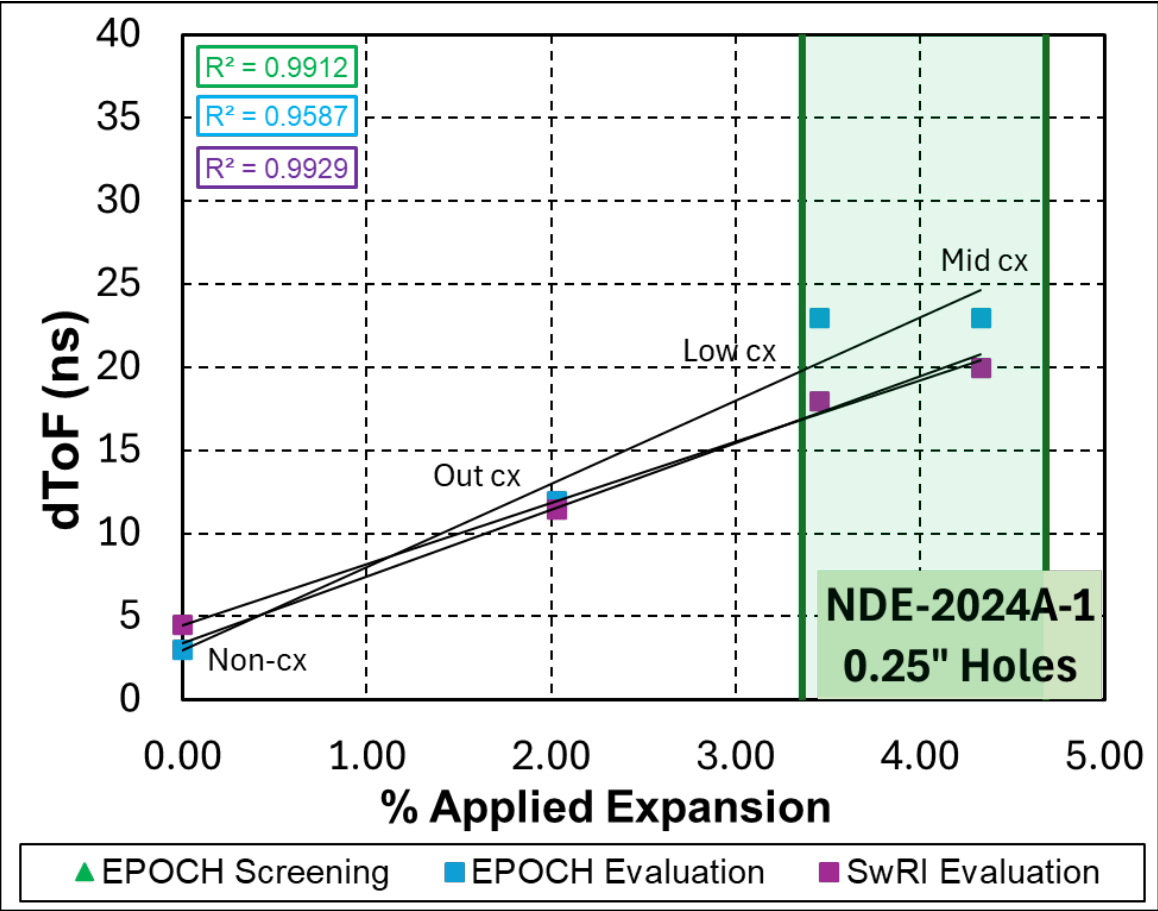
Equipment:

- COTS EPOCH650
- Custom SwRI system for higher fidelity data

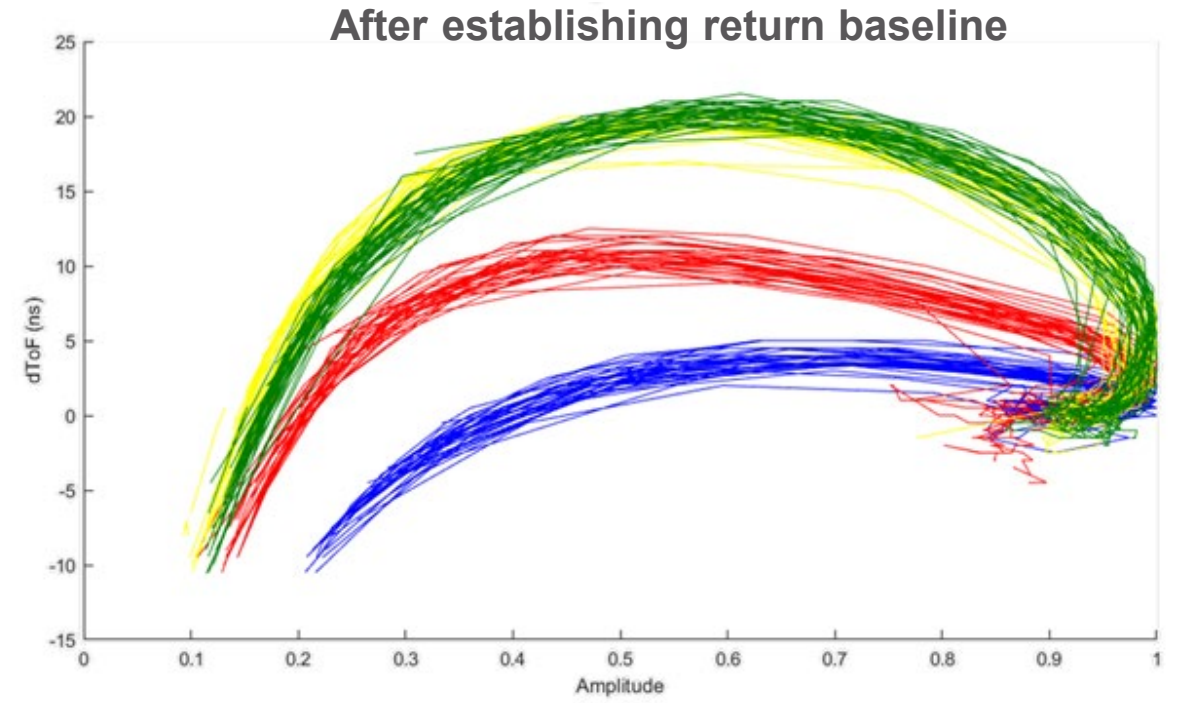
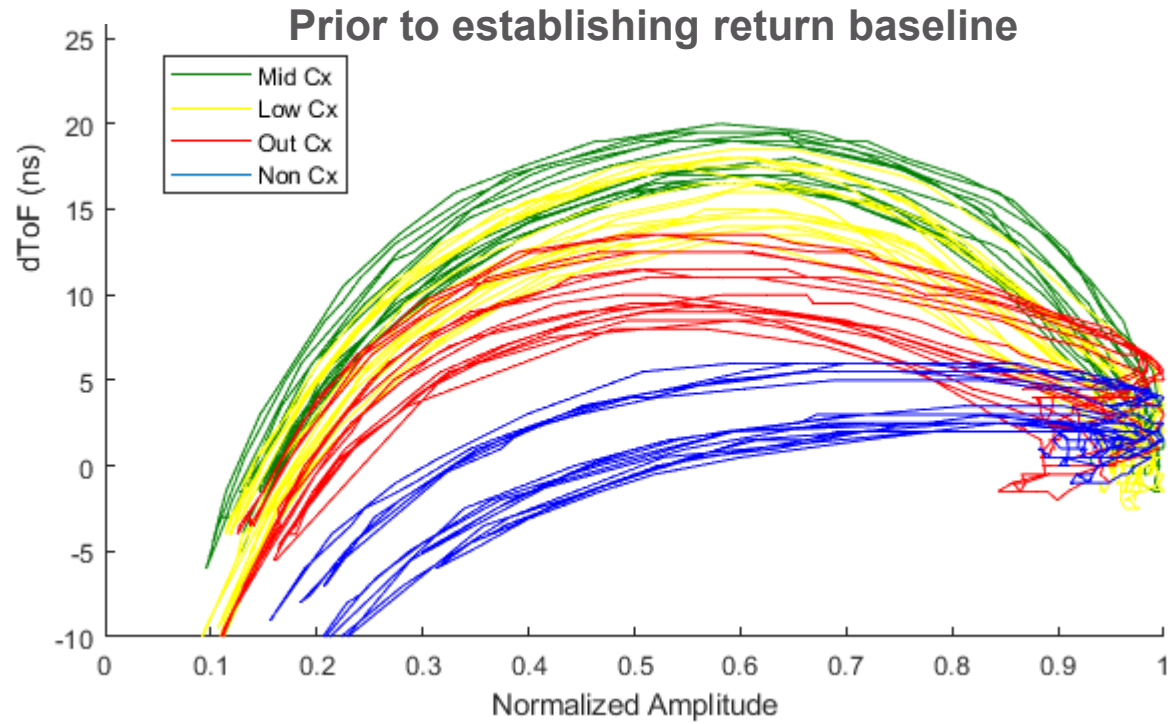


UT System Demonstration Video

UT Data Results



UT Data Results



ET LFEC In-Hole Probe

Full map of conductivity response, similar to the B-Scan captured by the EVi and ECS-5 tools

Post processing tool to view data

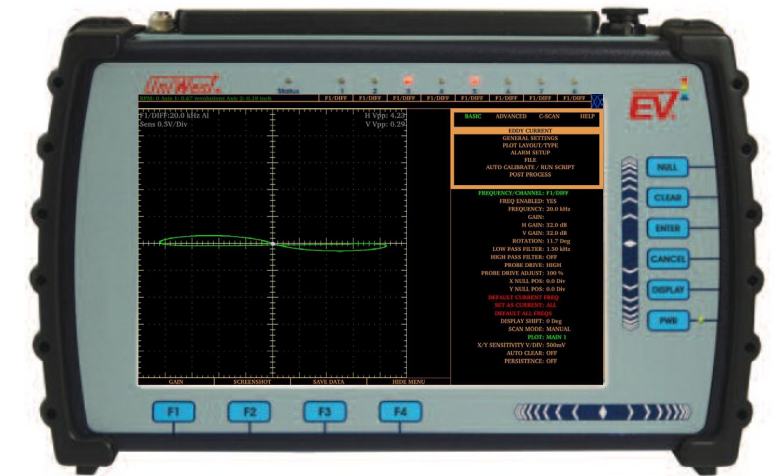
Capability to add post processing to EVi

Hardware components

- Eddy Current Instrument: EVi
- Bolt hole scanner: ECS-5s
- US-2871 and US-2863 LFEC probes

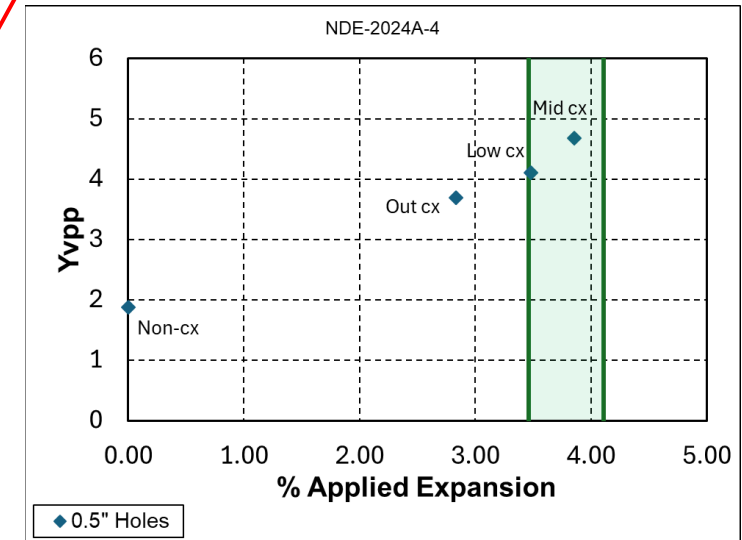
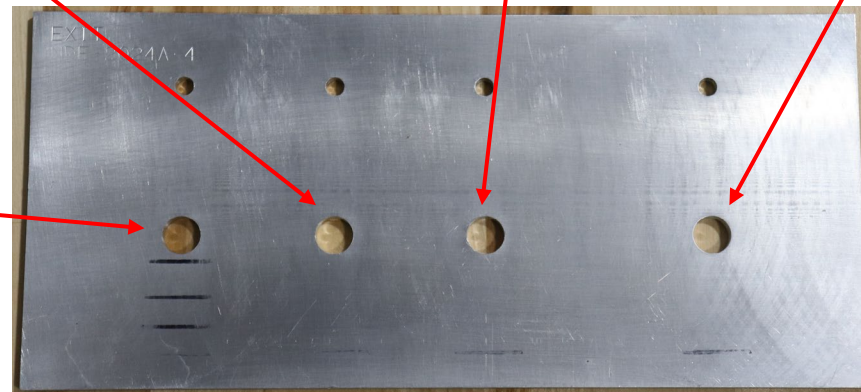
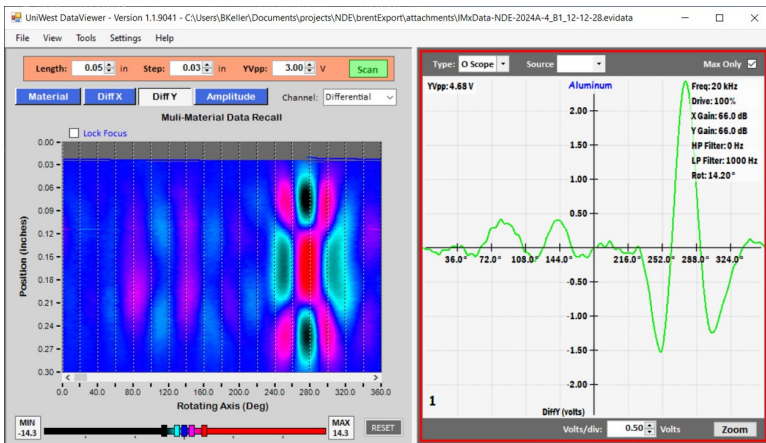
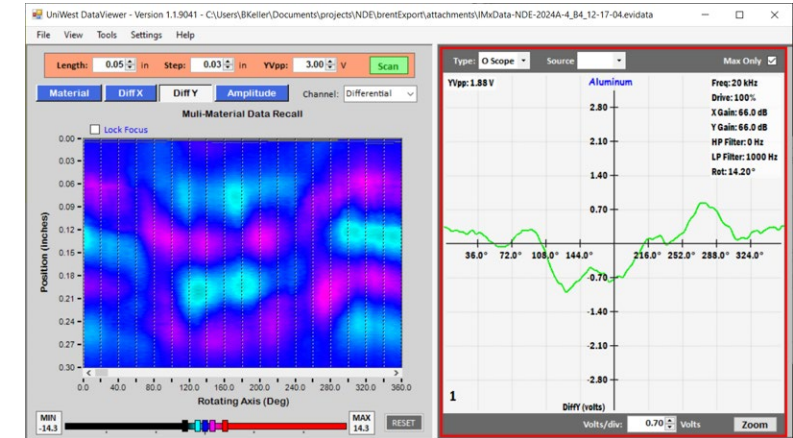
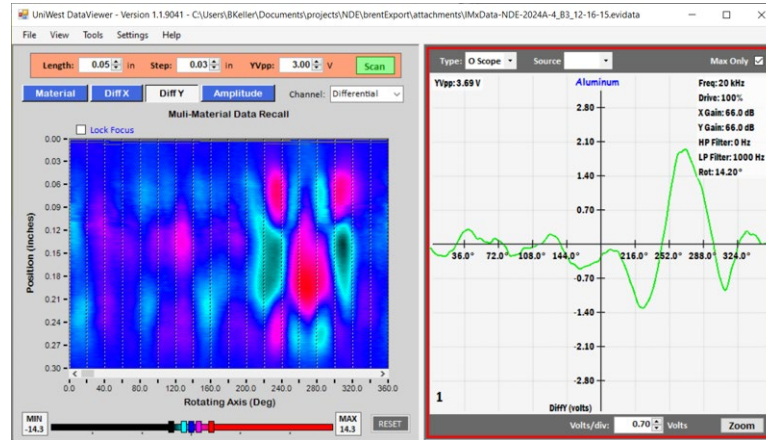
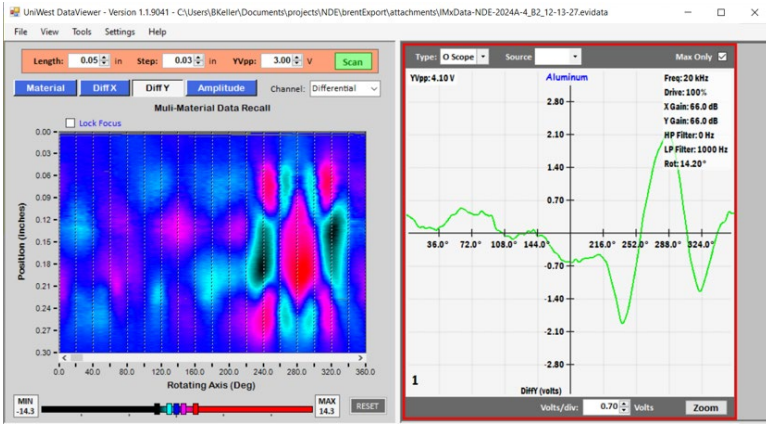
Procedure

- Set angle based on liftoff
- Set gain horizontal to achieve 80% FSW
- Increase Gain by 24 dB to increase signal amplitude



Task 4: NDE Technology Evaluation

Sample: EXIT NDE2024A-4 Bottom
 Thickness: 0.25"
 Hole Diameter: 0.50"



Conclusions

Current tasks remaining on SBIR Program

- Task 5: Technology Implementation-Ongoing refinements, new wedge designs, testing on a/c, etc...
- Task 6: Technology Demonstration

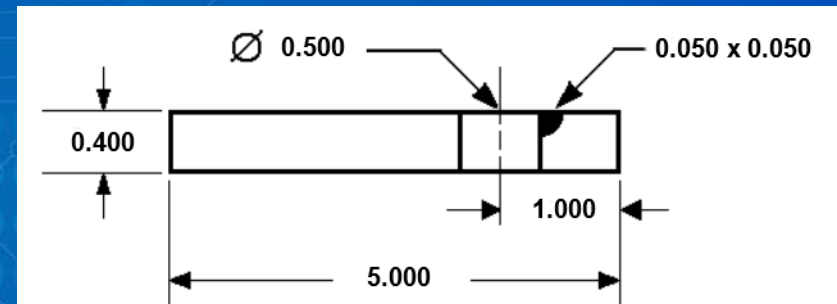
Upcoming program key tasks

- Task 2: NDE Technology Assessment for Titanium and Steel Applications
 - Utilize experience from previous programs to expand to aerospace titanium and steel materials
- Task 3: NDE Tech Assessment for Expanded Geometry Applications
 - Countersunk and filled hole conditions
 - Hole diameters ranging from 0.25 to 1.0 inch
 - Material thicknesses from 0.20 to 1.0 inch
- Task 6: NDE Technology Validation Study
 - Probability of Detection (PoD) Study

QUESTIONS?

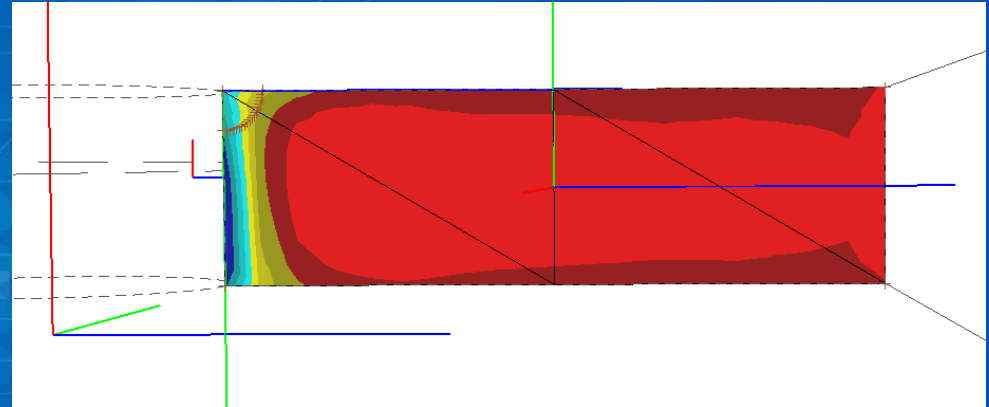
Damage tolerance inputs

- Initial flaw
- Geometric parameters
 - Width
 - Thickness
 - Hole diameter
 - Edge distance
- Material properties
 - Crack growth rates
 - Fracture toughness
- Spectrum loading
- Detectable flaw size

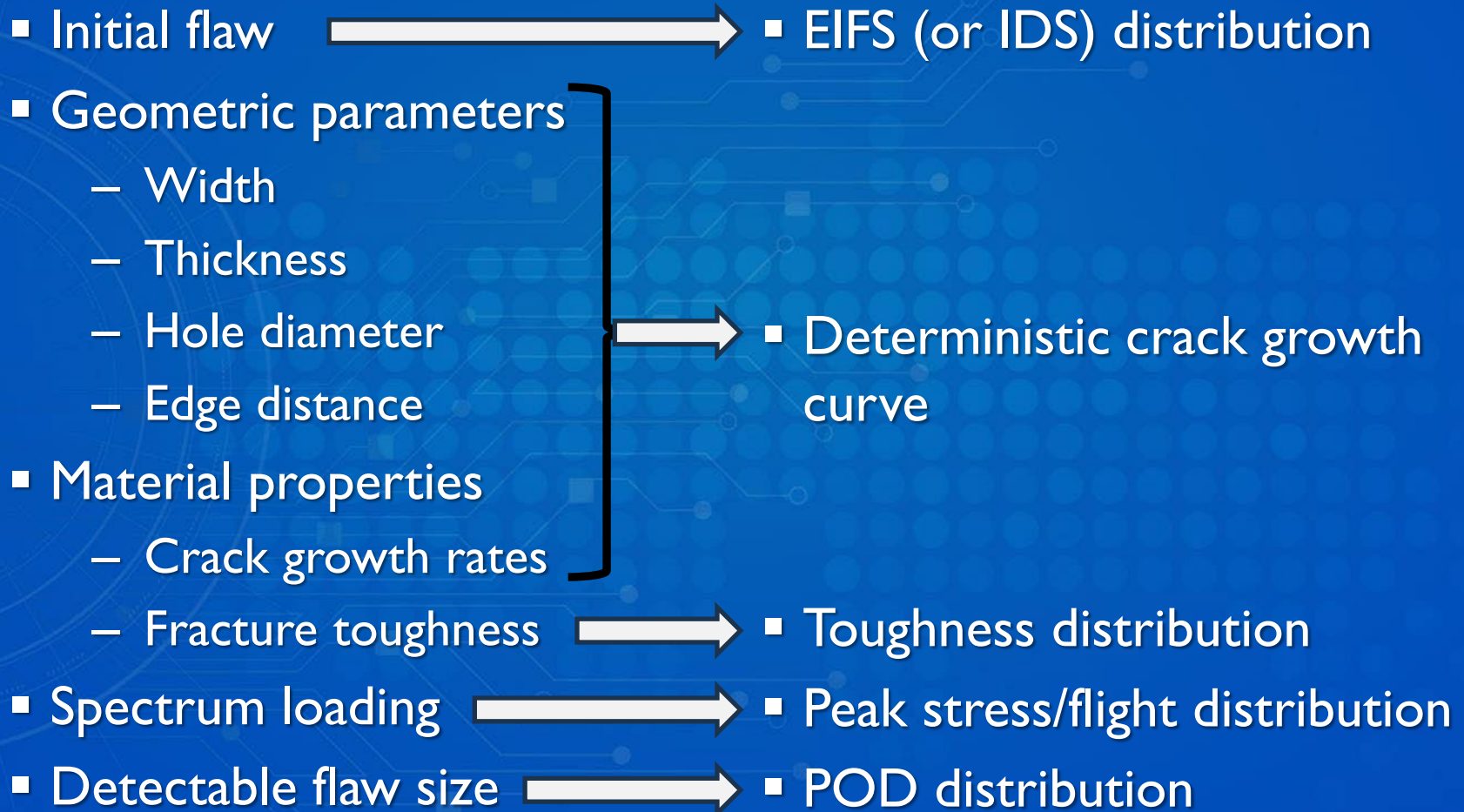


Damage tolerance inputs for Cx hole

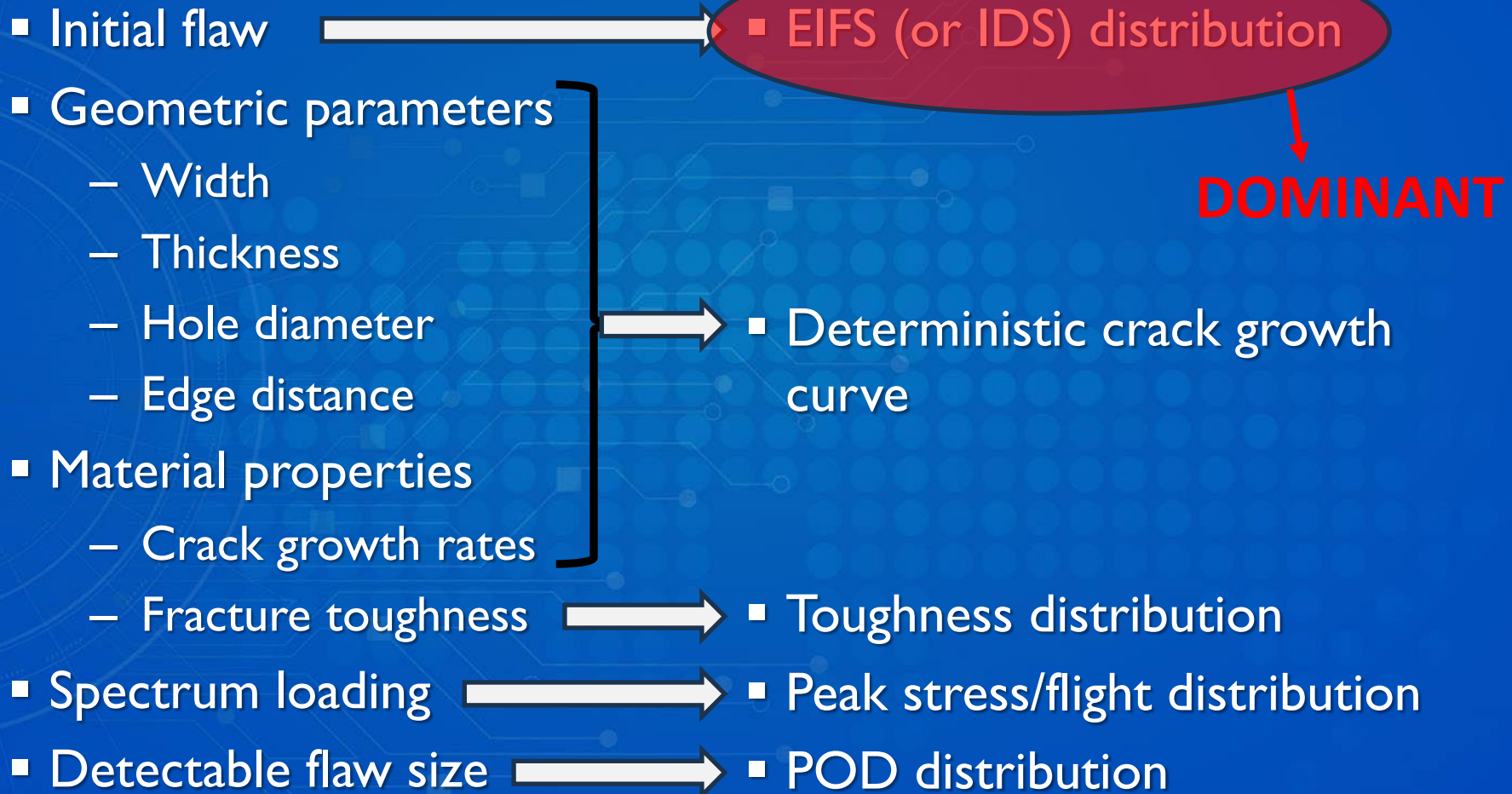
- Initial flaw
- **Residual stress field**
- Geometric parameters
 - Width
 - Thickness
 - Hole diameter
 - Edge distance
- Material properties
 - Crack growth rates
 - Fracture toughness
- Spectrum loading
- Detectable flaw size



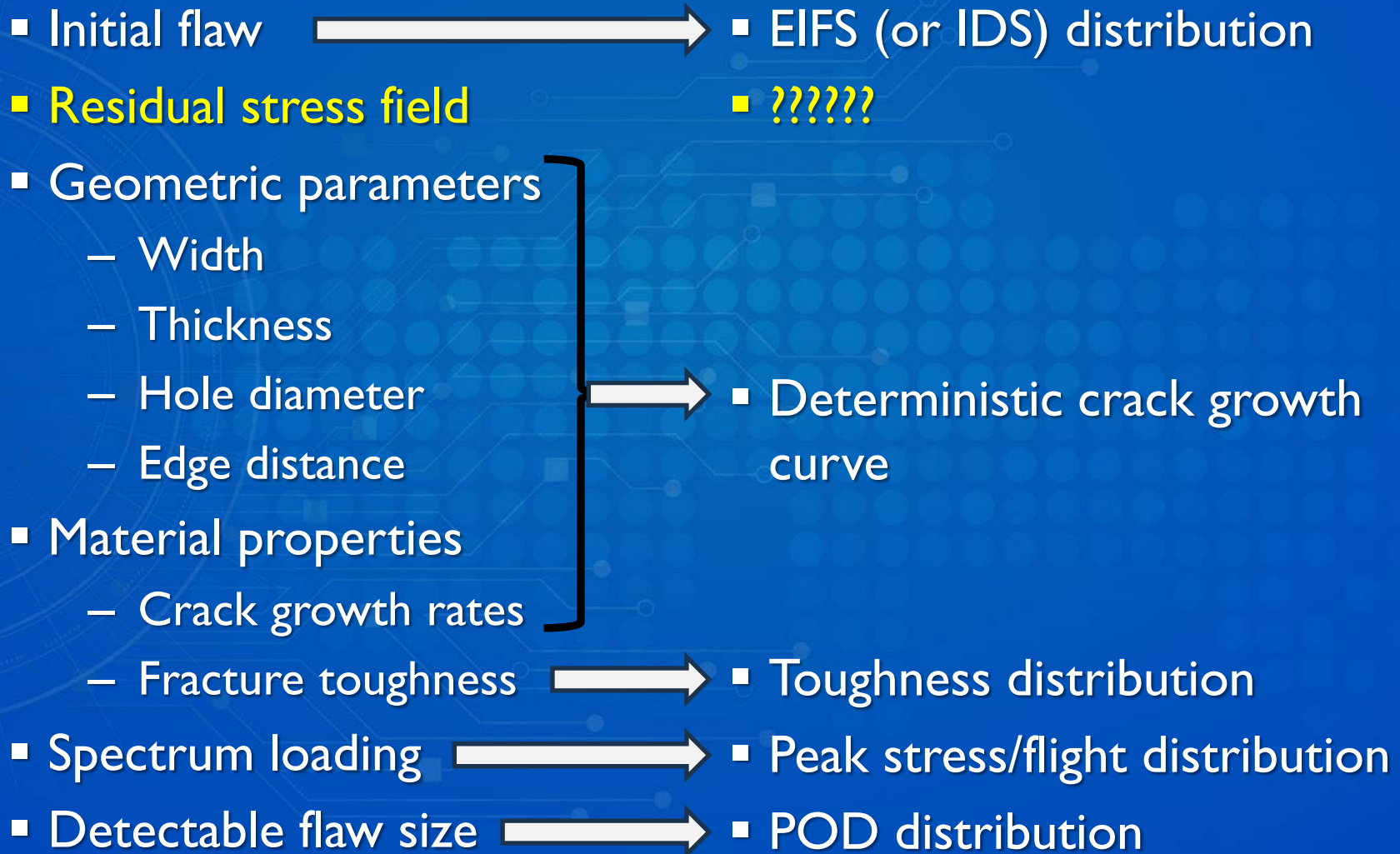
DT inputs feeding risk inputs in PROF



DT inputs feeding risk inputs in PROF



Cx DT inputs feeding risk inputs



How do we incorporate RS into risk?

- Option 1: Incorporate impact of (minimum?) residual stress into EIFS distribution and deterministic crack growth curve
 - Pro: Allows us to use existing PROOF framework
 - Con: Ignores the variability in the crack growth evident with different amounts of RS
- Option 2: Incorporate distribution of RS field into analysis, making the crack growth curve probabilistic
 - Pro: Much more realistic given the increased variability in growth with RS
 - Con: Need to understand the sensitivity from expansion to RS field to crack growth (What do we use as our random variable?)

ERSI Risk Analysis Break Out

Risk Analysis with Residual Stresses

Personal Experiences

- Performing risk analyses at structural locations that have accounted for residual stresses does not provide a great benefit if significant inspection data is not available to adjust the durability life
 - Inspections are managed using a durability flaw size
 - Risk cannot assume a smaller flaw size without data

Residual Stresses in Cold-Worked Holes

- Develop a risk procedure that utilizes the cold-worked data (pressure variance, # of holes, possible missed holes) to provide statistical insights into the benefits of the cold work holes
- I believe that the recorded data from engineered residual stress will continue to get better especially if we can show how that data will be used
 - Prove that the data is worth the additional cost of the tools

Futures Risk Analysis Topics and Projects

- What should the risk analysts be doing to help the ERSI team?
- Any ideas and topics that we should think about over the next year?

Risk Analysis Logic Tree Development

BLUF

- Develop an industry wide logic tree for handling various degrees of data at risk analysis locations
- Utilize coupon testing data (Scott Carlson) to create data sets that represents each portion of the logic tree
- Perform studies on the data sets to provide guidelines for defining the inputs
 - MLE vs MOM by median rank
 - Linear vs. non-linear regression
 - Distribution types

Contents

- Risk Scenarios
 - No inspection data
 - Inspection data no findings
 - Less than 10 (or some number)
 - More than 10
 - Multiple inspections
 - Inspection data with less than 3 findings
 - Is it possible to define a failure distribution/EIFSD
 - Inspection data with more than 3 findings
 - Inspection data with findings without details
 - Inspection data with great details
 - **More scenarios that I have not thought about**

Available Data

- 20+ coupons without engineered flaws and fractography
 - Multiple coupons with identical conditions (loading, grain direction, geometry)
- Plan would be to generate multiple datasets using both coupon data and fabricated data to represent each of the risk scenarios and work through the scenarios separately or as a group to develop a generic logic tree for analyst to reference when performing a risk analysis.
- The goal for the logic tree would be to create a best practices document for risk analyst to follow when performing structural risk analyses.