Air Force Life Cycle Management Center

Residual Stress Workshop: An ASIP Manager Perspective

U.S. AIR FORCE

15 September 2016

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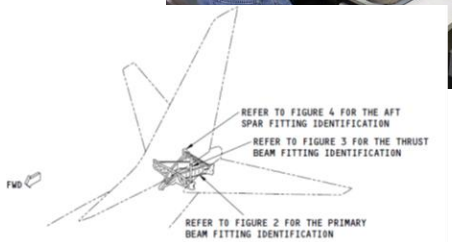
Overview

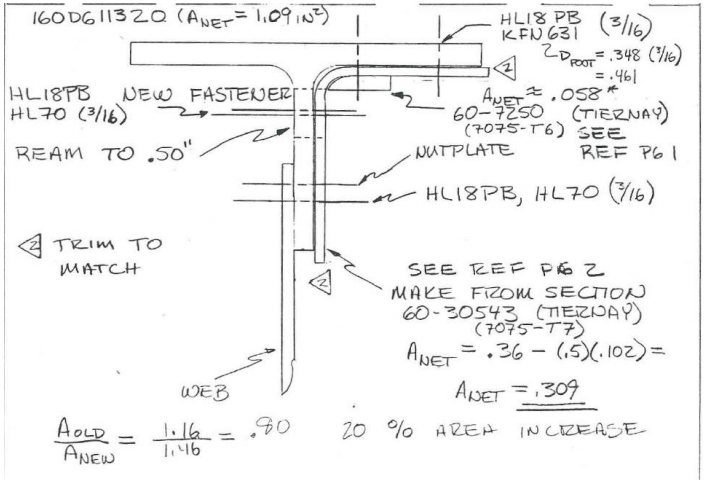
- Pre-History
- Recent Investments
- Completed Efforts
- In-Work
- Vision

Pre-History (1994-2005)

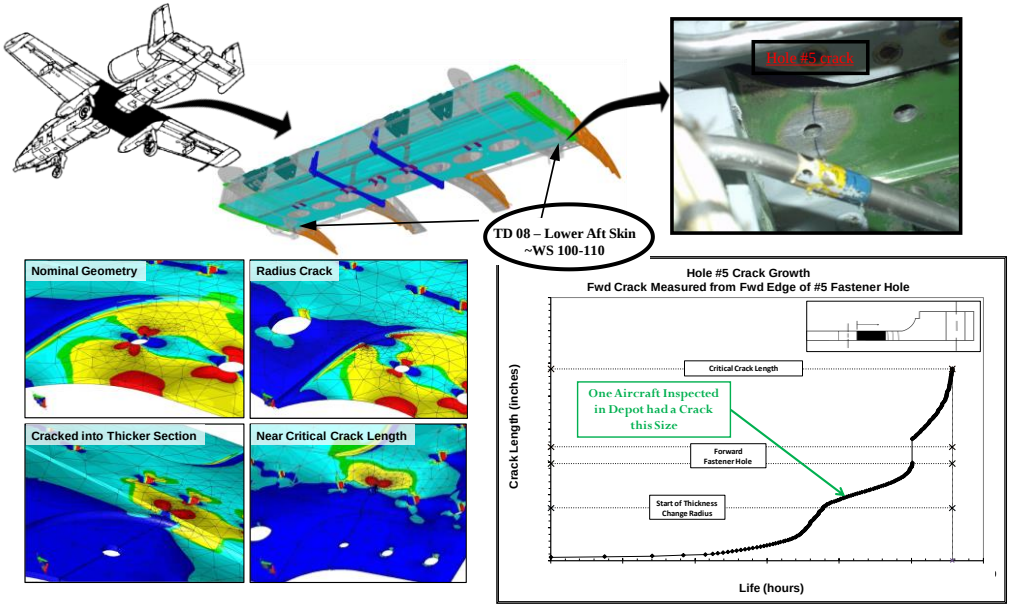


- Work with FTI® on cold expansion
  - 737 lap splice fleet improvement
    - Point design solution
  - 737 Texas-Star bushing migration
    - Improve retention
- Analytical Prediction of Residual Stress State and Influence on Fracture Mechanics Modeling
  - Simple relationship between residual stress and F_{ty}
  - Crack growth sensitivity through β - correction
- Palace Acquire (PAQ) Program
  - Provides Program Office an applied research avenue
  - Modernize fracture mechanics methods in general

Perspective



Example Repair (202 Disposition)
(A-10 Structures 2002)



Fleet Cracking (TCTO Support)
(A-10 Analysis Group 2008)

Analytical Basis

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Finite Element Analysis (Bootleg)

OGDEN AIR LOGISTICS CENTER

- Axi-symmetric 3-dimensional
  - Non-linear ABAQUS (Material)
  - W = 4”
  - T=0.25”
  - D = 0.5”
    - Nodal spacing near bore about 0.003” varies to 0.015” away from hole
- Hoop stress
  - May need to alter method to include radial and thickness stress components (Von Mises? Other?)
  - May need to consider the impact of toughness and F_{ty} in combination along with material hardening (?)

For Official Use Only

BE AMERICA'S BEST

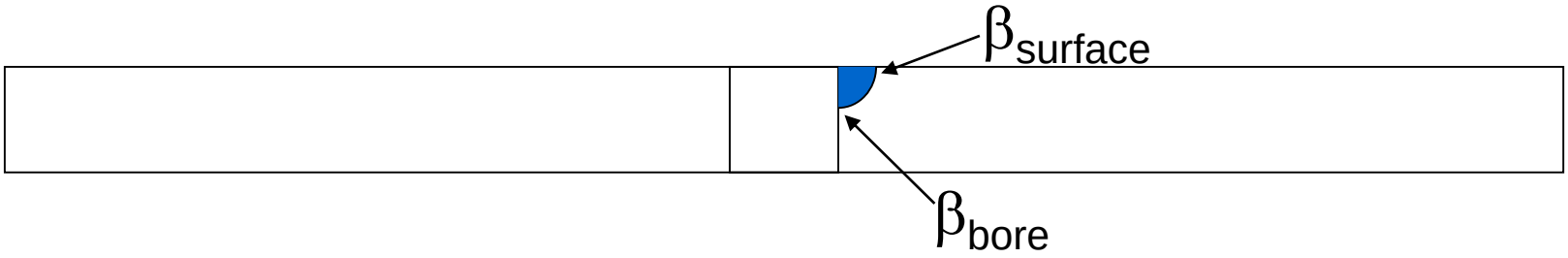
$$K = \sigma\sqrt{\pi a}\,\beta_{Detail}\beta_{Cx}$$

where

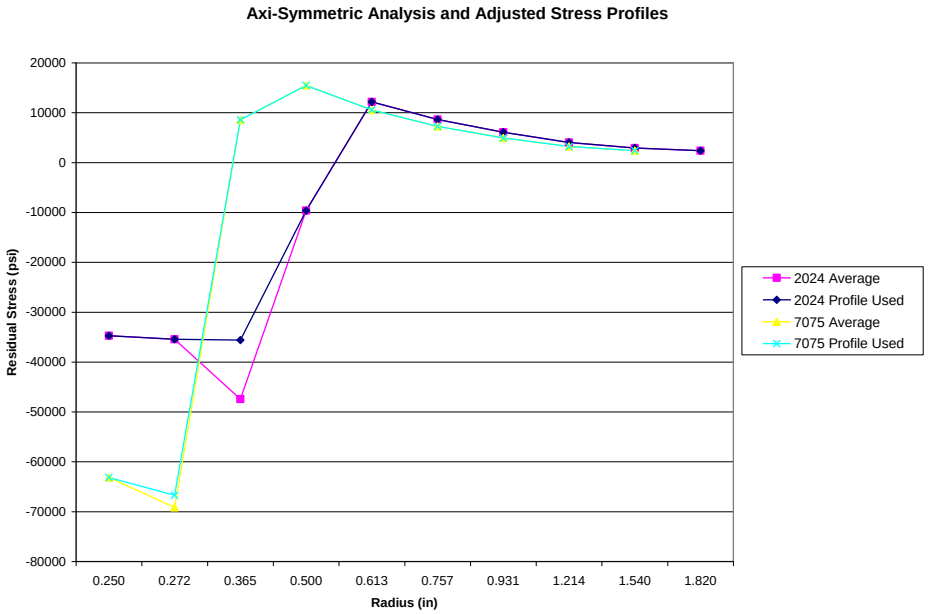
$$\beta_{Cx} = \frac{F_{ty} + \sigma_{Cx}}{F_{ty}}$$

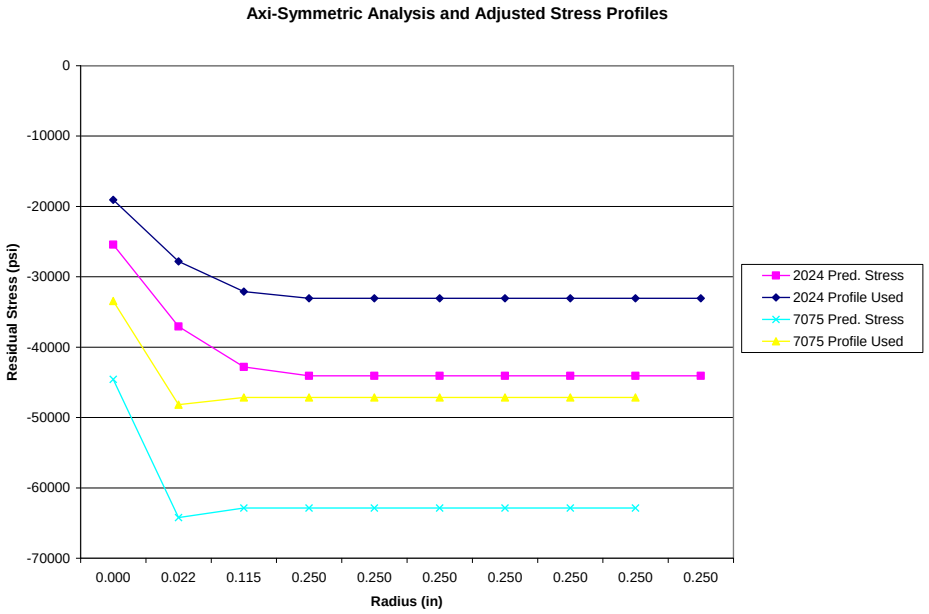
$$\sigma_{Cx} = F(Cx)$$

Comparative Model



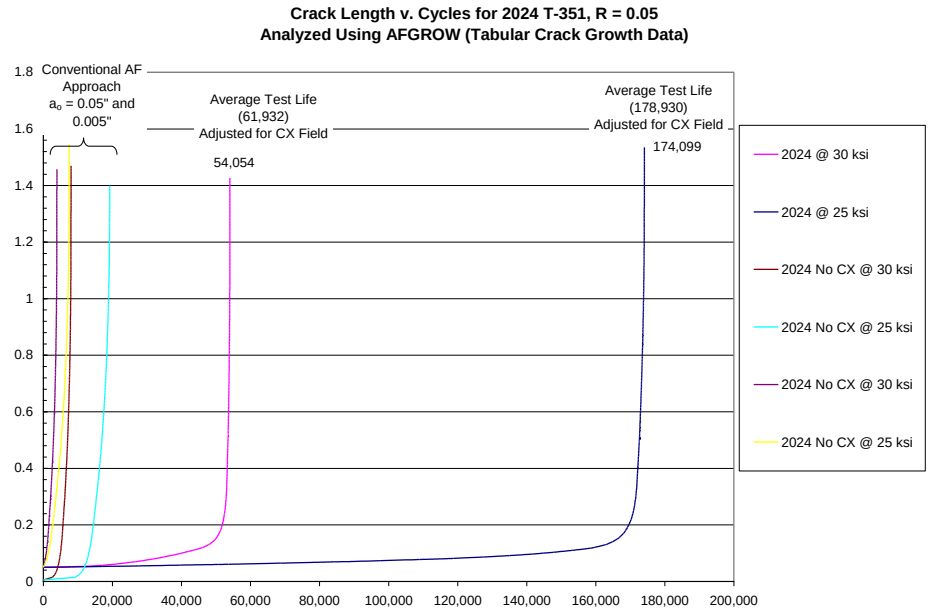
Adjustment

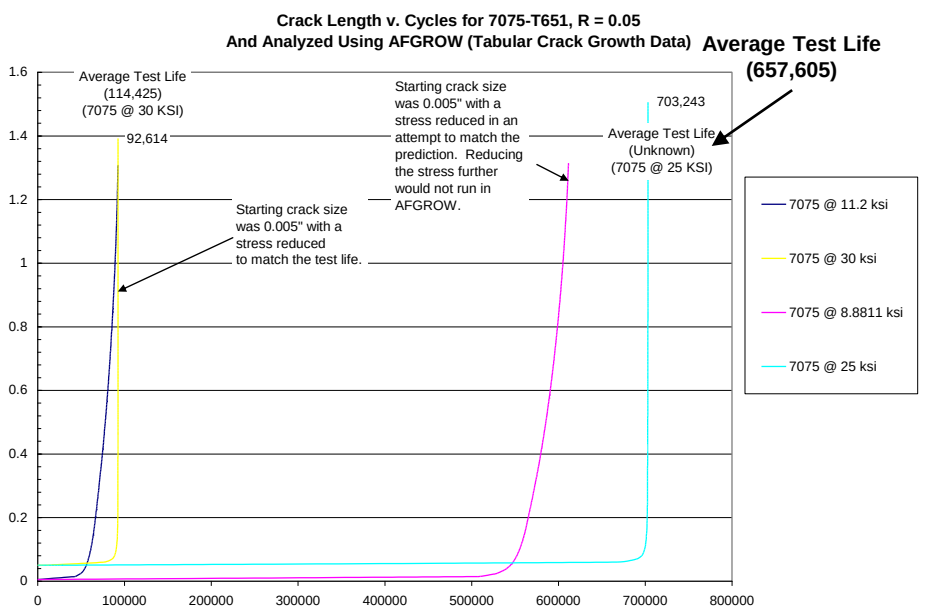

Axi-Symmetric Analysis and Adjusted Stress Profiles
Residual Stress (psi)
20000
10000
0
-10000
-20000
-30000
-40000
-50000
-60000
-70000
-80000
0.250
0.272
0.365
0.500
0.613
0.757
0.931
1.214
1.540
1.820
Radius (in)
2024 Average
2024 Profile Used
7075 Average
7075 Profile Used


Axi-Symmetric Analysis and Adjusted Stress Profiles
Residual Stress (psi)
0
-10000
-20000
-30000
-40000
-50000
-60000
-70000
0.000
0.022
0.115
0.250
0.250
0.250
0.250
0.250
0.250
0.250
Radius (in)
2024 Pred. Stress
2024 Profile Used
7075 Pred. Stress
7075 Profile Used

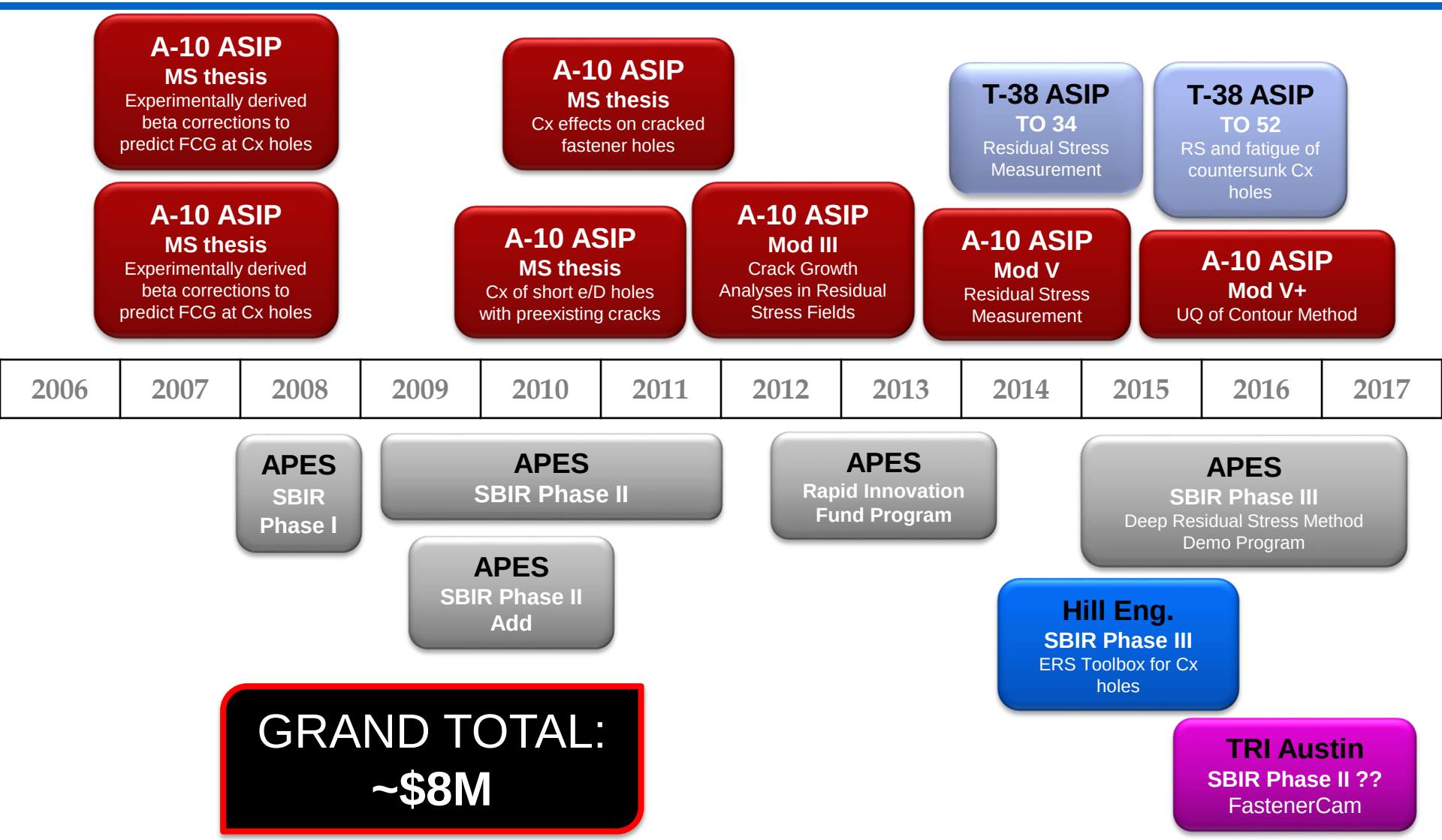
Test Comparison

- **Testing was performed by the Academy to compare cold expansion in stack-ups**
  - **NO Precrack**





Work Looking Into Residual Stresses



Completed Programs

Mod III: 38 total RS coupons
- Straight shank holes
- 2024-T351
  - Center hole, varying D
  - Center hole, varying %Cx
  - Offset hole, varying e/D
  - Multi hole, varying D
- 7075-T651
  - Center hole, varying D

APES Phase I, II, II-add SBIRs
- Life Prediction
- Residual Stress Relaxation
- Understanding Failure
- 2024-T351 & 7075-T651
  - 10 RS Coupons
  - 70+ Fatigue Tests
  - Straight shank holes

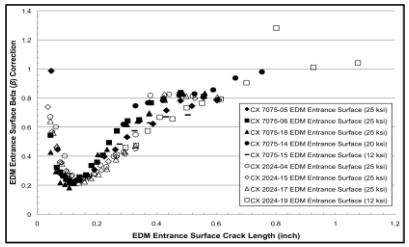
T-38 TO 34: 15 total RS coupons
- 3 Straight hole coupons
- 12 Csk hole coupons
- 7075-T7351
- Vary Cx process
  - Cx then Csk
  - Cx csk hole with CsCx
  - Cx csk hole w/o CsCx
- 3 hole (3 coupons)
  - Identify effect of pitch

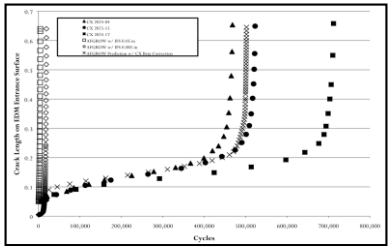
A-10 Mod V: 12 total RS coupons
- Straight shank holes
- Center hole
- Varying process:
  - No ream
  - Standard Ream
  - Double Cx

APES Rapid Innovation Fund
- Three Technology Areas
  - Life Prediction
  - FastenerCam (800+ holes)
  - NDT (118 coupons)
- 7 Materials
- Various Spectra
- Many geometric variables
- Large amounts of data
  - 200+ fatigue tests
  - 70 RS Coupons

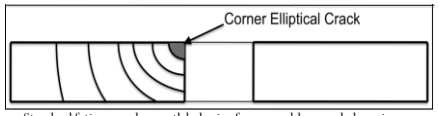
A-10 Masters Thesis Work
- Life Prediction
- Two materials
- Various load spectra
- Various peak stress levels
- Center hole & Low e/D
- 70+ Fatigue Tests

Application-Based Research Efforts

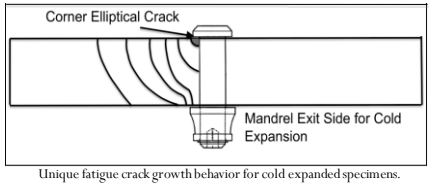




Impact of Cold Expansion (CX) on Crack Growth

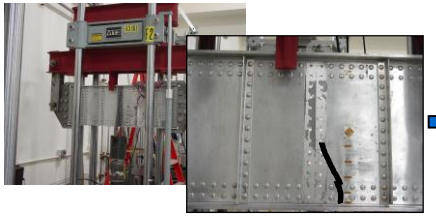


Standard fatigue crack growth behavior for non cold expanded specimens.

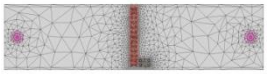


Unique fatigue crack growth behavior for cold expanded specimens.

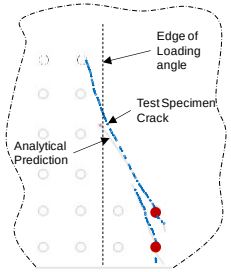
Image of experimental fatigue crack growth.



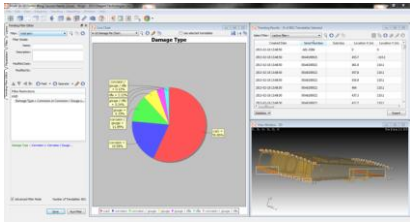
Test



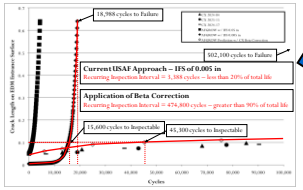
Analysis



Validation



Rapid Innovation Fund
MX Data Visualization



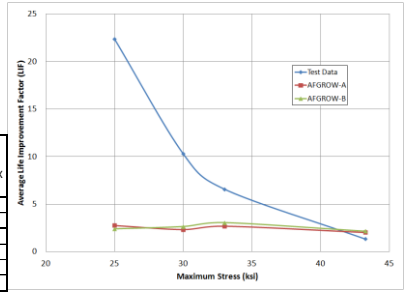
Analysis v. Test

Spar Web Analysis

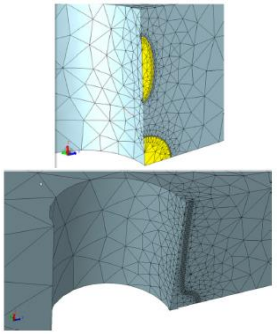
Impact of Cold Expansion (CX) on NDI

- LIF decreases with increasing stress

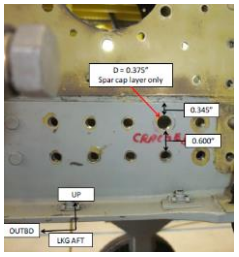
Loading	Max Stress (ksi)	Non-CX Life (cycles)	PC-CX Life (cycles)	LIF NCX to PC-CX
Constant Amplitude	20	47443	4296067	90.6
	25	7443	452585	60.8
Spectrum	25	31521	704450	22.3
	30	N/A	194950	10.3
	33	12201	80220	6.6
	43	4658	6201	1.3



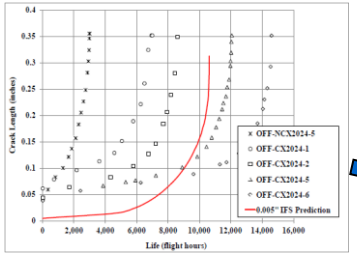
Influence of Spectrum Peak Stress on Benefits of CX



Rapid Innovation Fund
CX-Residual Stress Characterization

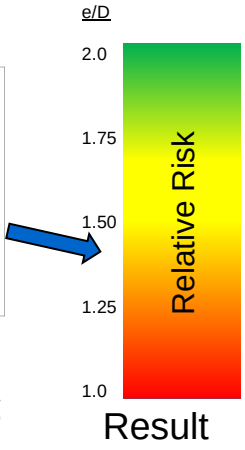


Rework Requirement



Test

CX Edge Margin Sensitivity



Result

Currently In Work

T-38 TO 52
- Fatigue Life Prediction in Cx Csk Holes
  - Three Cx methods
- 30 Fatigue Tests
- 26 Residual Stress

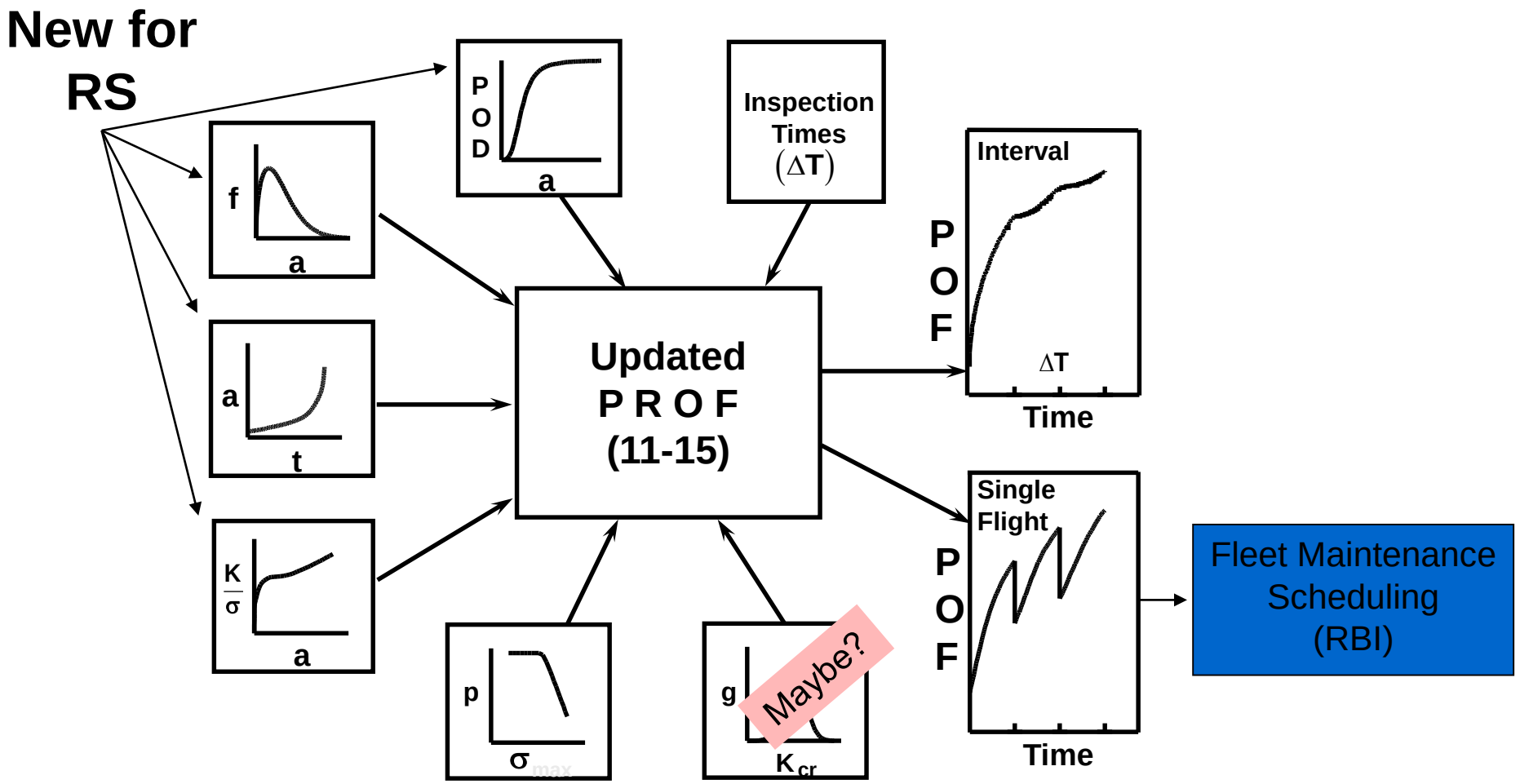
Phase III SBIR -- APES
- Stress Redistribution Due to Crack Propagation
- Material Models & Response
- Filled Hole
- Loaded Hole
- 80 Fatigue Tests
- 40 RS Distributions

A-10 Mod V+: UQ Effort
- Primarily an Analysis Task
- Quantify Uncertainty Qssociated with Contour Method
  - Inter-Laboratory round robin

Phase III SBIR --Hill Engineering
- Legacy Cx Compared with New Production
- 110 RS Coupons
  - 80 off aircraft
  - 30 new material
- 34 Fatigue Coupons

Phase II SBIR –TRI Austin
- FastenerCam Evolution
  - Countersunk holes
  - Non-Contact
- Not on Contract yet….Dave???

Risk Comments



Or something altogether new?

Overall Vision

- Improve Understanding of Deep Residual Stress Quantification Uncertainty
  - Influence of current measurement processes on residual stress quantification (Best Practices)
  - Influence of aging on residual stress treatments
  - Sensitivity of crack propagation predictions through statistical characterization (Quasi-Allowable)
- Evolve Crack Propagation Data Collection Processes to Complement Analytical Capabilities
- Further Develop Non-Destructive Inspection Methods to Validate and Correlate Treatments to Benefits
- Implement through Comprehensive Qualification