2017 Residual Stress Summit, UDRI, OH

Aircraft Structural Integrity Program (ASIP) Perspective on Accounting for Engineered Residual Stress in Damage Tolerance Analysis

24 October 2017

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Outline

- **USAF ASIP**
- **Damage Tolerance in ASIP**
- **USAF Engineered Residual Stress Experience**
- **3 Primary Technical Needs**

Why Does USAF Have ASIP?

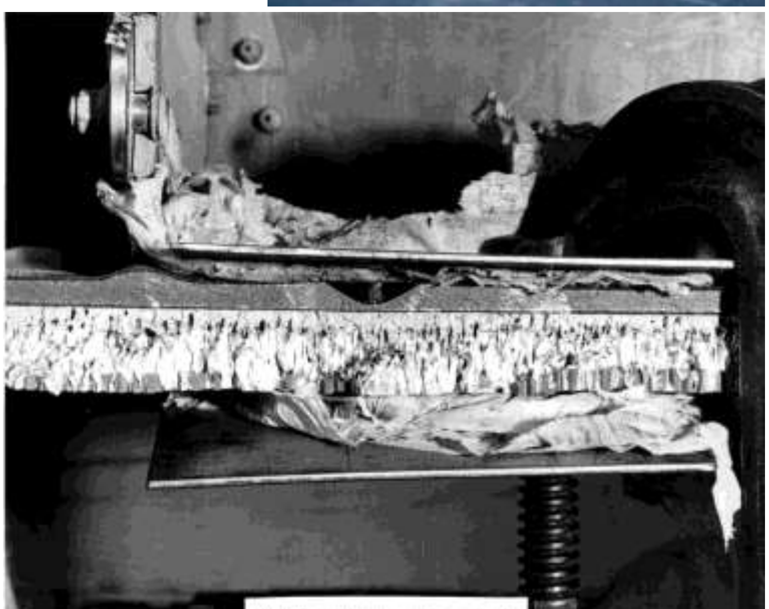
- **Established 12 June 1958 in response to 4 B-47 aircraft losses in 1 month due to fatigue failure of a/c structure**

Aircraft	Date	Failure Location	Number of Flight Hours	Cause of Failure
B-47B	13-Mar-58	Center Wing, BL 45	2,077	Fatigue
TB-47B	13-Mar-58	Center Wing, BL 35	2,419	Fatigue
B-47E	21-Mar-58	Disintegration	1,129	Fatigue
B-47E	10-Apr-58	Wing to Fuse Fitting, FS 515	1,265	Fatigue
B-47E	15-Apr-58	Disintegration	1,419	Overload?

Ref: ASC-TR-2010-5002

Why Damage Tolerance in ASIP?

- **F-111 loss on 22 December 1969 and F-5 loss on 20 April 1970 demonstrated ASIP fatigue controls not effective**
  - **F-111 structural failure due to fatigue cracking from a manufacturing defect (design unable to tolerate damage)**



Damage Tolerance Implementation

- ASIP provides 3 methods to satisfy the damage tolerance requirement in MIL-STD-1530D (Ref. 1)
  - Slow damage growth; required for single load path
  - Fail-safe multiple load path
  - Fail-safe damage-arrest
- Damage tolerance assessments were performed and the results were used to modify the maintenance programs
  - 1971-1975: B-1A, C-5, F-4, A-7, F-16, C-141
  - 1976-1980: E-3, F-5, T-38, T-39, KC-135, SR-71, KC-10, A-10, B-52, F-111, F-15
  - 1981-1985: C-130, B-1B, T-46, HH-53, C-17
  - 1986 & on: implemented at program start

A/C Safety Since Damage Tolerance

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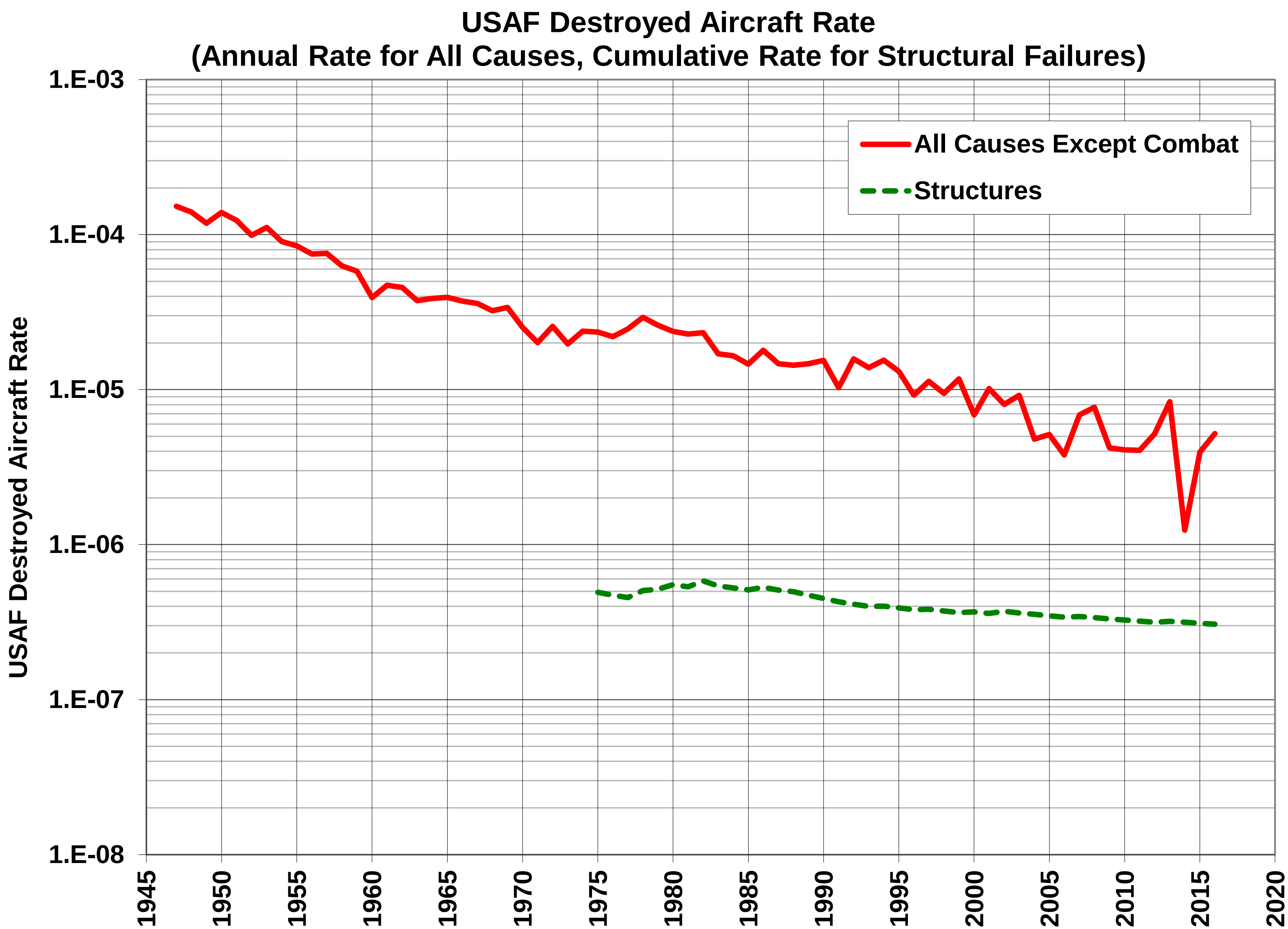


Summary of USAF Experience

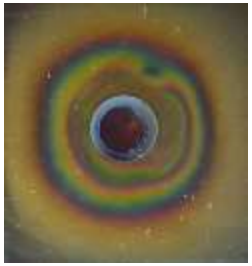
- **Unacceptable aircraft safety record prior to establishing inspection & MX requirements based on damage tolerance philosophy**
  - **Primary threat – fatigue cracking in metallic structure!**
- **Aircraft loss rate since damage tolerance was implemented appears to be acceptable**
  - **However, occasional aircraft losses due to structures still occur; notable example is F-15C in November 2007**
  - **Damage Tolerance (DT) based inspections have also found unanticipated damage in nearby locations that would not have been found otherwise (additional safety benefit that has not been quantified)**

Primary Threat to Structural Integrity Continues to be Fatigue Cracking in Metallic Structure!

Engineered Residual Stress (ERS)

- USAF has significant experience with utilizing & relying upon ERS to increase DT inspection intervals in safety-of-flight structural locations
  - Numerous applications of interference fit fasteners
  - Numerous applications of cold expanded (CX) holes
  - More recently, Laser Shock Peening (LSP)
- Original USAF DT requirements (Ref. 2) limited the beneficial effects to be used in design ("partial credit")
- Current USAF practices include using the same "partial credit" method during sustainment; until validated analysis & inspection methods exist to take "full credit"

“Partial Credit” Example



- **EZ-SB-17-001 (Ref. 3) provides a method for cold expanded (CX) holes**
  - Utilizes Equivalent Initial Damage Size (EIDS) method
  - Relies on DT tests with CX holes
  - Compare durability crack growth analysis (no ERS) with DT tests (with ERS)
    - Iterate EIDS until total life is matched (no attempt to match crack growth rate, etc.)
  - Limit benefit to EIDS = 0.005” corner crack if smaller size results from step above

Approach to Take “Full Credit”

- **Consider the 5 factors for new materials, processes, joining methods and/or structural concepts in MIL-STD-1530D (paragraph 5.1.7)**
  1. **Stable: established process to impart ERS?**
  2. **Producible: validated Quality Assurance (QA) or Non-Destructive Evaluation (NDE) method?**
  3. **Characterized properties: known ERS field and known damage growth rates through ERS field?**
  4. **Predictable performance: validated DT Analysis (DTA) method?**
  5. **Supportable: validated QA/NDE and Non-Destructive Inspection (NDI) methods during sustainment phase?**

1. Need Established ERS Process

- **Stable ERS process should have:**
  - Defined process limitations (e.g., particular material, specific geometries)
  - Specifications for tooling, equipment, etc.
  - Process specifications
  - Manufacturing instructions
  - Qualified personnel
- **Stable ERS process should result in:**
  - Consistent & repeatable quality
  - Predictable costs for implementation

2. Need Validated QA or NDE Method

- **Need validated QA (fully automated ERS) or NDE (manual ERS) method to verify ERS attained as intended (confirm DTA with ERS applies) considering:**
  - **Tooling, equipment, etc. variability**
  - **ERS process variability**
  - **QA/NDE accuracy**
- **QA/NDE results should be:**
  - **Quantitative**
  - **Retained as permanent record**
  - **Auditable**

3 & 4. Need Validated DTA Method

- Need accurate prediction of crack growth rate through 3D residual stress fields for:
  - Material application
  - Specification range of applied work/energy
  - Various geometries (e.g. e/D)
  - Various loads spectra (e.g. R-ratio effects)
  - Occasional overloads/underloads (e.g. load interaction)
  - Effects of crack on ERS changes
  - Effects of multiple cracks

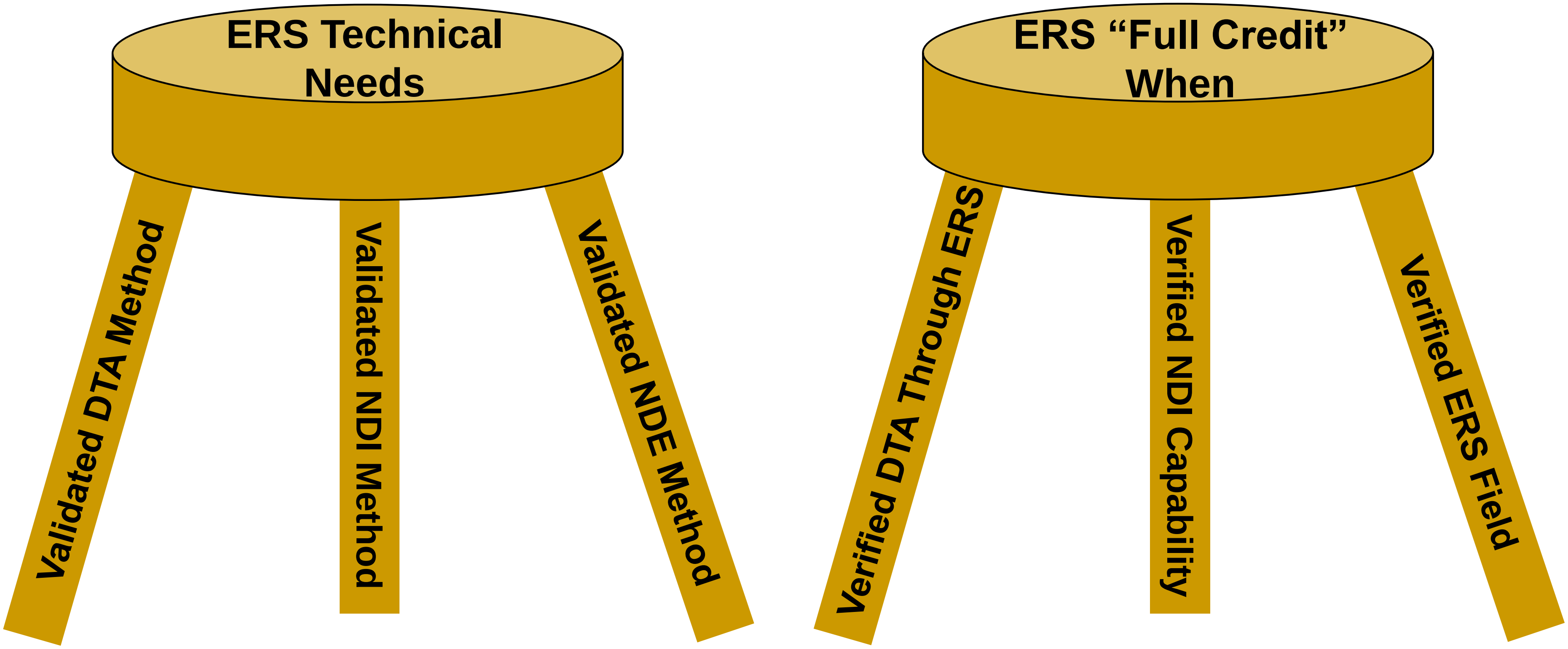
5. Need Validated QA/NDE & NDI Methods During Sustainment

- **Initial inspection (based on ½ life from DT initial size[(2)] to critical size with ERS):**
  - **Need validated QA/NDE method to verify ERS attained as intended (confirm DTA with ERS applies)**
- **Recurring inspections (based on ½ life from "detectable"[(3)] size to critical size with ERS):**
  - **Need validated NDE method (same ERS still present?)**
  - **Need NDI POD for each NDI method**
    - **Impact of ERS on crack detectability[(3)]**
    - **For CX, NDI access on mandrel entry or exit face?**

(2) ERS during initial production: assumed size; ERS during sustainment: detectable size
(3) Typically 90% Probability of Detection (POD) with 95% confidence

Summary

- **3 primary technical needs must be satisfied for each stable ERS process to take "full credit" during entire aircraft sustainment phase**



Let's Work Together to Get There!

References

1. **MIL-STD-1530D, "Aircraft Structural Integrity Program", 13 October 2016**
2. **MIL-A-83444, "Airplane Damage Tolerance Requirements", 2 July 1974**
3. **EZ-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**

From MIL-STD-1530D: "(Copies of U.S Air Force Structural Bulletins are available from AFLCMC/EZSS, Bldg. 28, 2145 Monahan Way, Wright-Patterson AFB, OH 45433-7017; 937-904-5476; Engineering.Standards@US.AF.MIL.)"

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