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PROBABILISTIC LIFING OF A SECOND OVERSIZE HOLE MODIFICATION

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Probabilistic Lifing of a Second Oversize Hole Modification

Outline

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  - Current Problem
  - Standard Methodology
- Proposed 2nd OS Analysis Methodology: Baseline Approach
- Proposed 2nd OS Analysis Methodology: Enhanced Approach
- Conclusion

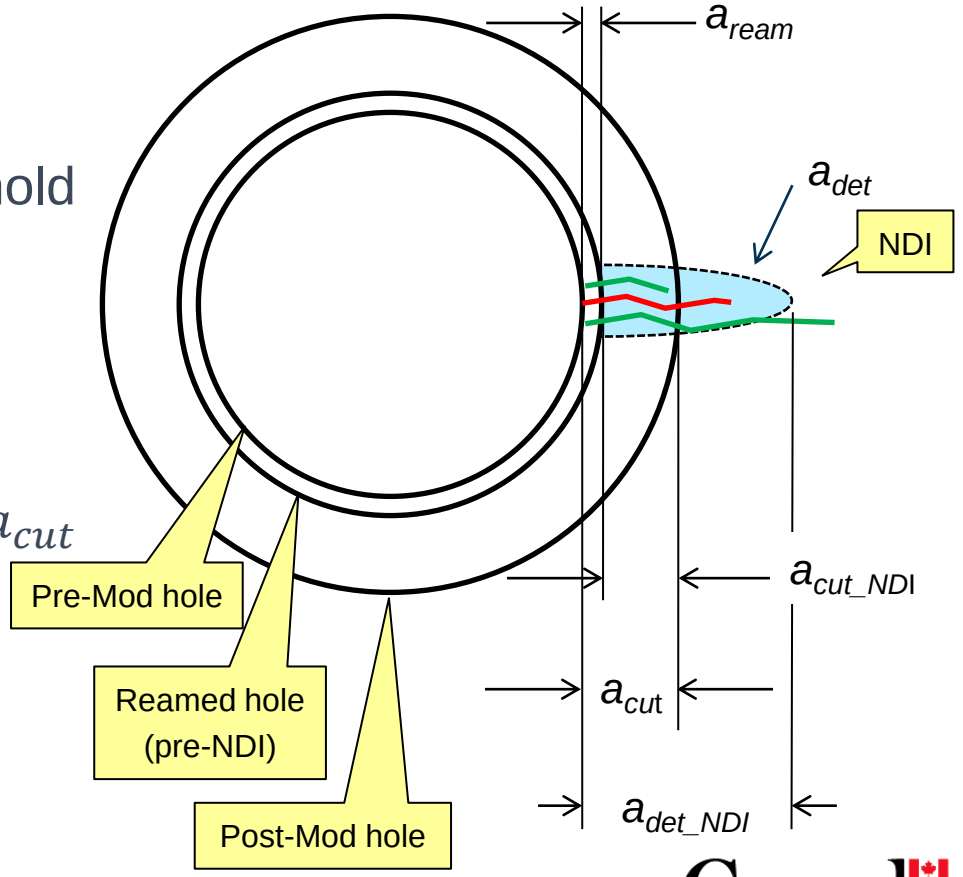
BACKGROUND

Current Problem
Standard Methodology

Background
Nomenclature

Typical 2nd Oversize (OS) Hole Modification Characteristics

1. The hole is reamed (a_{ream})
2. Non-destructive inspection (NDI) is performed
   - a_{det} ($a_{90/95}$) is typically assumed as detection threshold
   - Cracks larger than $a_{det} + a_{ream}$ prior to reaming are likely detected → hole repair
3. The hole diameter is increased
   - Typically a 0.36 to 0.41 mm (0.14”-0.16”) radial cut, a_{cut}
   - Undetected cracks smaller than a_{cut} prior to reaming are removed
   - Remaining cracks up to $a_{res} = a_{det} + a_{ream} - a_{cut}$ may exist after the Mod



Background

Current Problem

Life of Several CF188 Life Limiting Items with 2nd OS Mods is Too Short

- Early in the CF-188 life, the 2nd OS Mod was considered a confidence cut leading to a full life reset
- After some usage, cracks may become too large to be completely removed by the OS, yet too small to be detectable with high confidence by NDI
- Current guideline: If factored "CI" life* is passed, a Post-Mod crack is assumed to be present
- Causes likely unnecessary costly inspections for several Life Limiting Items (LLI).

- **Could a probabilistic approach be used to decrease conservatism?**

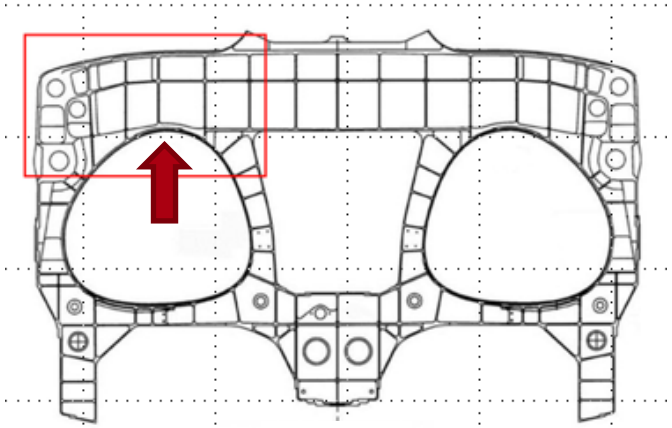
* Factored crack initiation life: probability $a \geq 0.254$ mm (0.01") = 0.001

Background

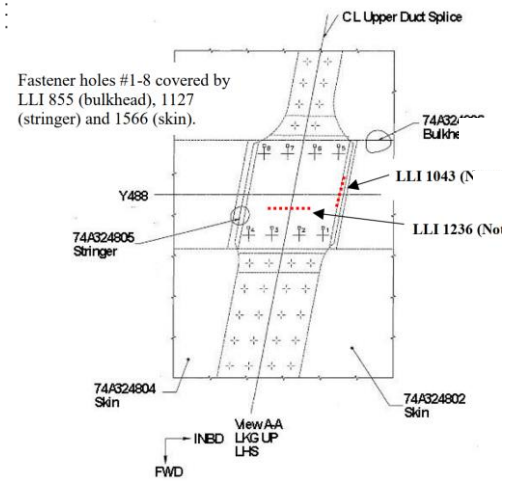
Standard Analysis Methodology (Safe Life Approach)

Example: Life Limiting Item (LLI) 855

- Analysis assumptions (prior to the OS Mod):
  - 8 holes = 1 article, 2 articles per A/C
  - “CI” life distribution (life to 0.254 mm or 0.01”) available from in-service inspection (pre-Mod)
  - Crack growth (CG) life distribution and CG curve derived from full-scale test (from 0.254 mm to 10.44 mm, or 0.01” to 0.411”)
  - Safe Life Limit (SLL) = **80.9% of target life**



Y488 Bulkhead

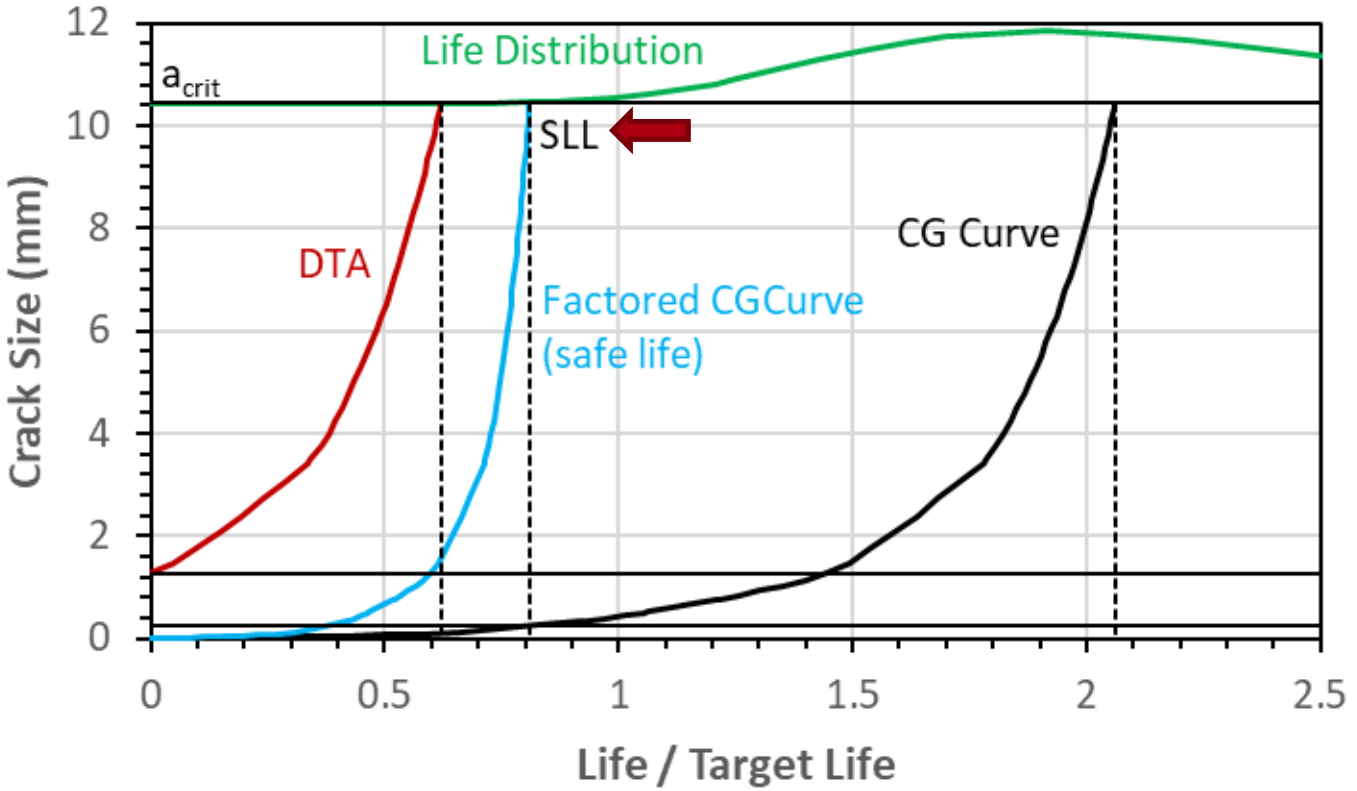


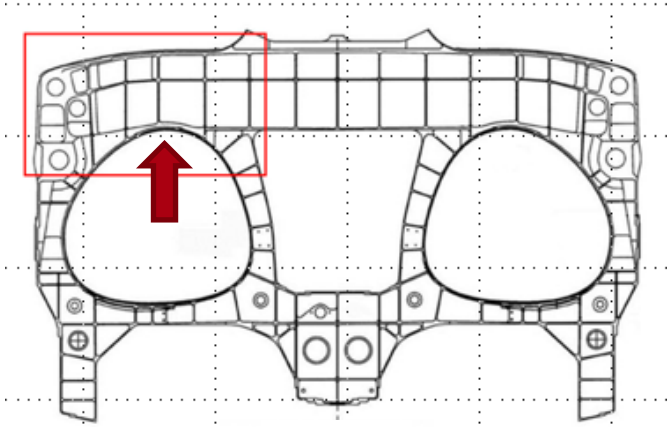
LLI 855

Background

Standard Analysis Methodology (Safe Life Approach)

Example: Life Limiting Item (LLI) 855





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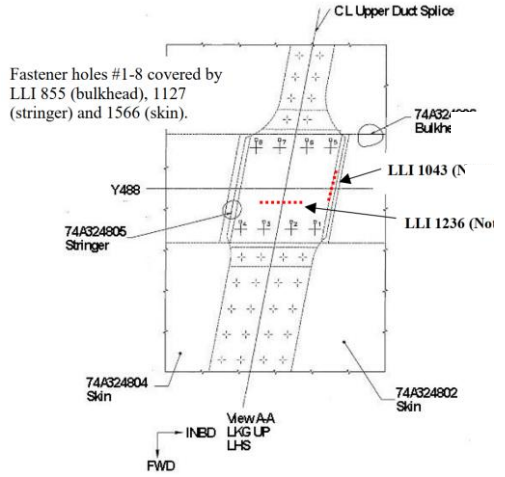


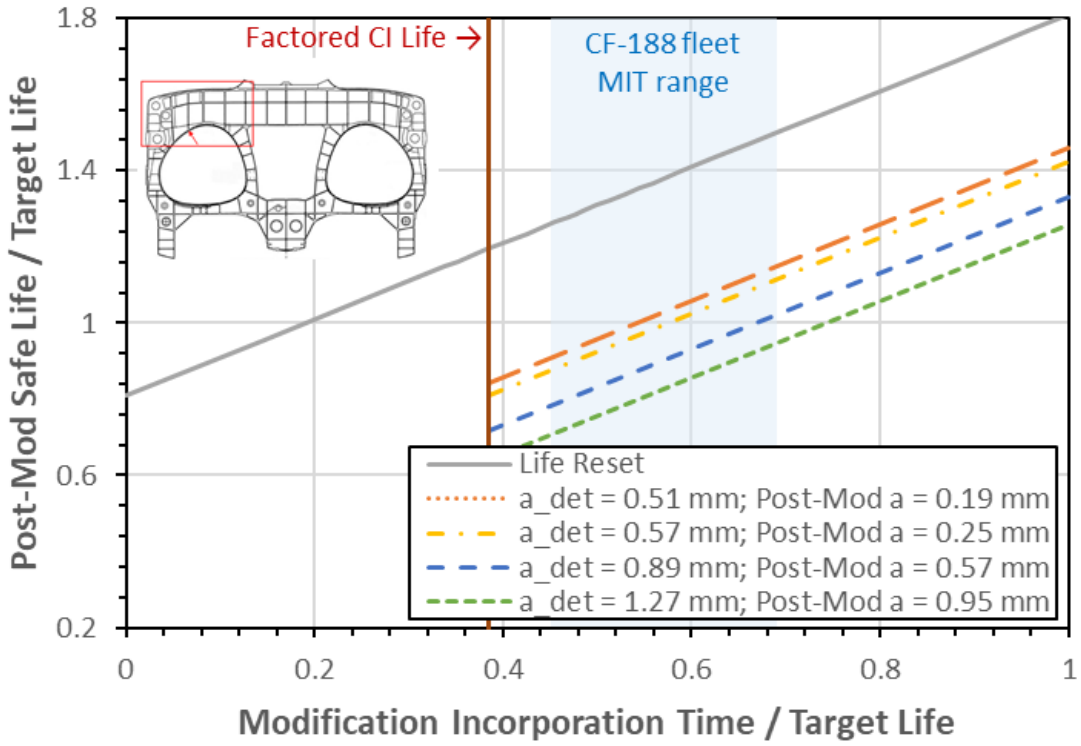
LLI 855

Background

Standard Analysis Methodology (Safe Life Approach)

Example: 2nd OS ALEX Modification 6.0 on LLI 855

- Average Modification Incorporation Time (MIT) is 57.3% of the fleet Target Life
- Minimum material removed (a_{cut}) = 0.36 mm
- "Critical" crack size: a_{crit}= 10.44 mm
  - Acceptable residual strength in full-scale testing
- Mod at average MIT does not reach Target Life if a_{det} is larger than 0.57 mm
  - Post-Mod a = 0.254 mm



By definition, there is a probability of only 0.1% that a crack reaches 0.254 mm at the Factored CI Life

PROPOSED 2ND OS HOLE MODIFICATION ANALYSIS METHODOLOGY

Baseline Approach

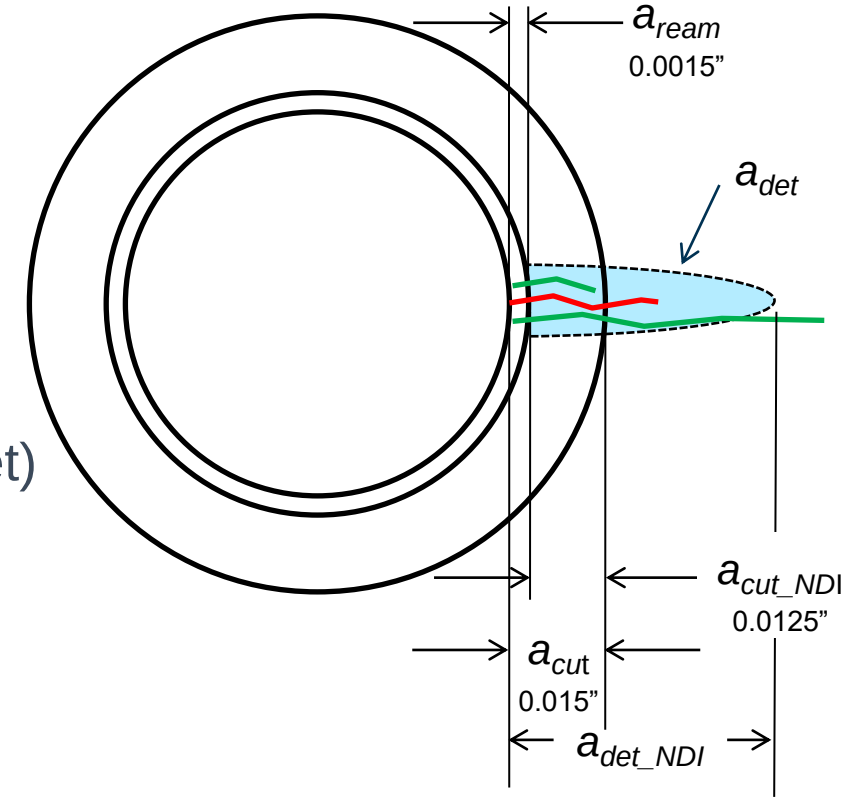
Baseline 2nd OS Mod Analysis Methodology

Concept Overview

Baseline Approach

Simulate crack inspection/repair from crack size distribution predicted at the MIT (CF-188 lifing methodology)

- Cracks with $a < a_{cut}$ → life reset
- Cracks with $a_{cut} < a < a_{det} + a_{ream}$ → POD (hit/miss)
  - Detected cracks: repaired (life reset)
  - Undetected cracks assumption: $a_{res} = a_{det} + a_{ream} - a_{cut}$
- Cracks with $a > a_{det} + a_{ream}$ → detected & repaired (life reset)
- Detectability based on POD of $a_{cut} - a_{ream}$ (post-reaming)
- Growth of the residual cracks are used to calculate the probability of failure (POF)



Baseline 2nd OS Mod Analysis Methodology

Concept Overview

Crack Size Distribution at Modification Incorporation Time (MIT)

- SLL is determined as MIT + t such as:

$$CPOF(t)_{PM} = P(A)\,P(B)\,CPOF(t) = 0.0005$$

Equivalent to cumulative POF of 0.001 per A/C (2 articles per A/C)

- $P(A) = P(a_{cut} < a < a_{det} + a_{ream})_{MIT}$: Probability of a having a crack larger than a_{cut} that can be missed by NDI
- $P(B) = 1 - POD(a_{cut} - a_{ream})$: Probability of missing a crack that was left
- $P(A)P(B)$: Probability of having a Post-Mod residual crack
- Method:
  - Determine the remaining life t that results in the acceptable CPOF
  - Calculate the Post-Mod SLL as MIT + t

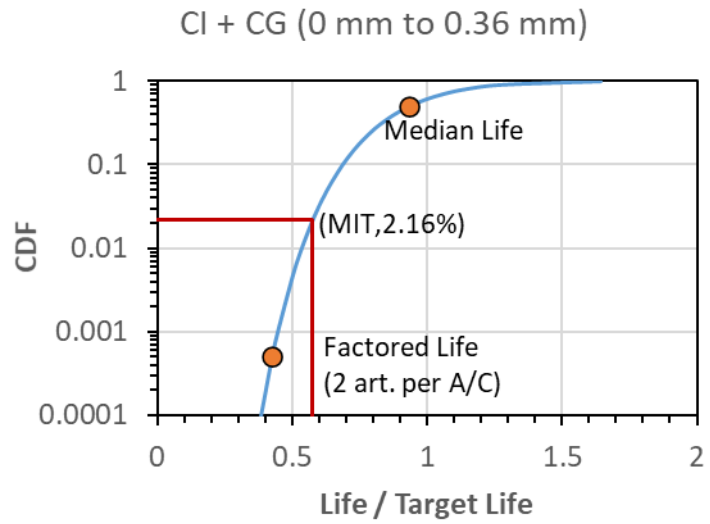
Baseline 2nd OS Mod Analysis Methodology

ALEX Modification 6.0 Example (LLI 855) at Average MIT

a_{ream} = 0.04 mm (0.0015”) a_{cut} = 0.36 mm (0.014”)
a_{crit} = 10.44 mm (0.411”) a_{det} = 0.57 mm (0.0225”)
MIT = 57.3% of target fleet life

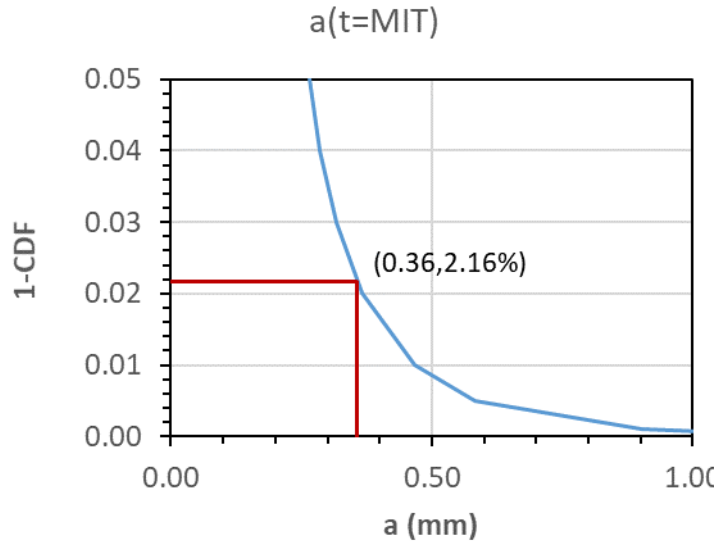
Probability of having a crack with $a_{cut} < a < a_{det} + a_{ream}$

- Calculated from P(life<MIT) for a or P(a) at average MIT
- $P(A) =$ **2.16% - 0.60% = 1.56%**



Probability of missing a crack of $a_{cut} - a_{ream}$

- After pre-NDI ream (probability of missing a 0.32 mm crack)
- $P(B) =$ **50%** (assumed from coupon study)



Probability of having a Post-Mod residual crack

- $P(A)P(B)$ **= 1.56% X 50% = 0.78%**

Baseline 2nd OS Mod Analysis Methodology

ALEX Modification 6.0 Example (LLI 855) at Average MIT

CG time for acceptable risk level (0.0005 per article for a 2 article A/C)

- $POF(t)$ **= 0.0005 / 0.78% = 6.39%**
- Residual life to acceptable risk = 75.4% of Target Life (starting from 0.254 mm or 0.01")
- SLL = MIT + CG t = 57.3% + 64.7% = **132.7% of Target Life for average MIT**

More conservative assumption

- POD=0
  - $P(A) = P(a_{cut} < a)_{MIT}$
  - $P(B) = 1$
- SLL = **122% of Target Life for average MIT**

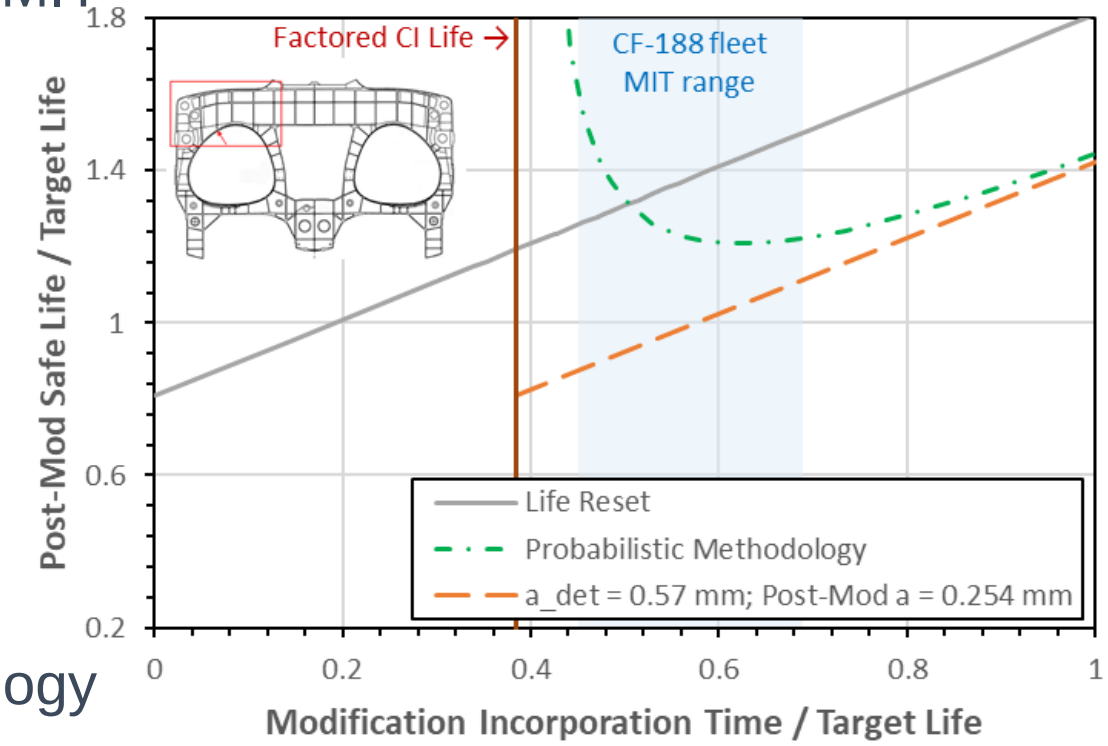
Baseline 2nd OS Mod Analysis Methodology
Discussion

Limitations

- The Post-Mod SLL neglects the contribution of removed or detected/repaired cracks to the POF, which is unconservative for an early MIT
- a_{det} may not be representative of the true in-service detection capabilities
- The Post-Mod residual crack size is independent of the MIT

Proposed Enhancements

- Include all cracks in POF calculations
- Use representative POD curve
- Calculate a_{res} distribution from lifing methodology



PROPOSED 2ND OS HOLE MODIFICATION ANALYSIS METHODOLOGY

Enhanced Approach

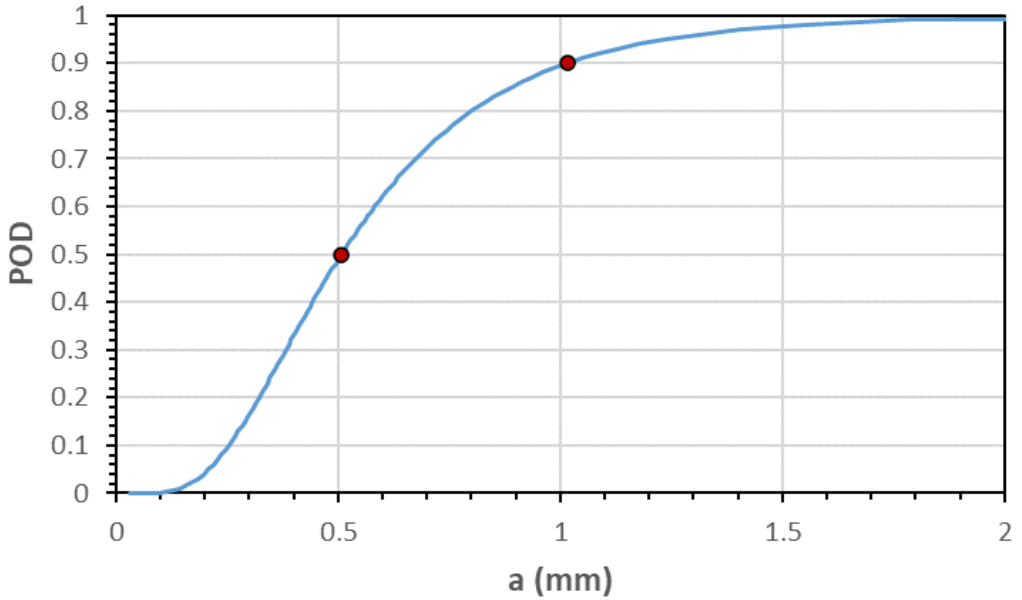
Enhanced 2nd OS Mod Analysis Methodology

Concept Overview

Two populations of cracks contribute to the POF / SLL:

1. Cracks that are completely removed and cracks that were detected + repaired
   - Crack detection uses a complete POD curve acting on the $a - a_{ream}$ distribution at MIT
   - Full life reset is assumed for detected cracks
2. Cracks that are reduced but not completely removed
   - Remaining crack size is the distribution of $a - a_{cut}$

The SLL is calculated based on a mixture of these two crack populations



Bair, R. *et al.* (2018), "In-Service Inspection Crack Size Assumptions for Metallic Structures", EN-SB-08-012, Revision D, the United States Air Force.

Enhanced 2nd OS Mod Analysis Methodology

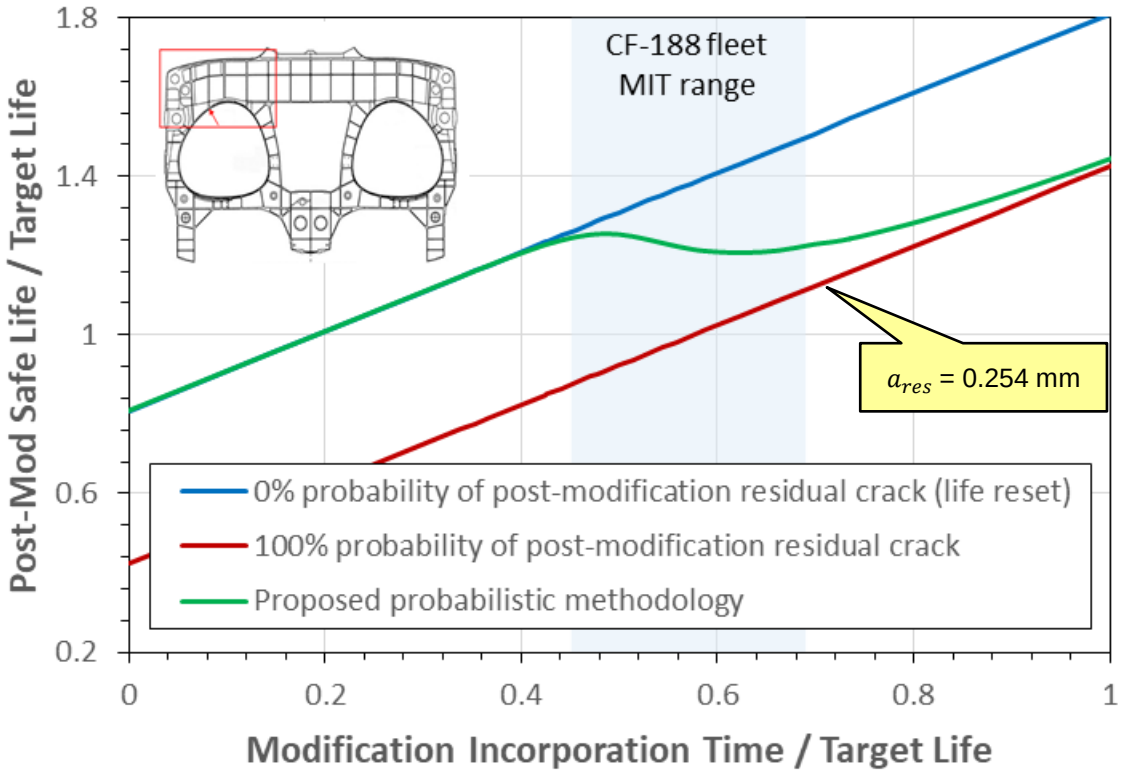
Improvement 1

A/C-Specific Implementation

- Assumption: POD = 0
- Cracks completely cut → Life Reset (conversion to full CG model)
- Cut cracks → Life from 0.254 mm (0.01”)
- Post-Mod SLL = Individual MIT + mixture of two populations (life reset + CG)
- Safe Life Limit (SLL): CPOF of 0.001 per A/C

Observation:

- All C/C in the fleet have a post-Mod life > 125% of the Target Life



Enhanced 2nd OS Mod Analysis Methodology

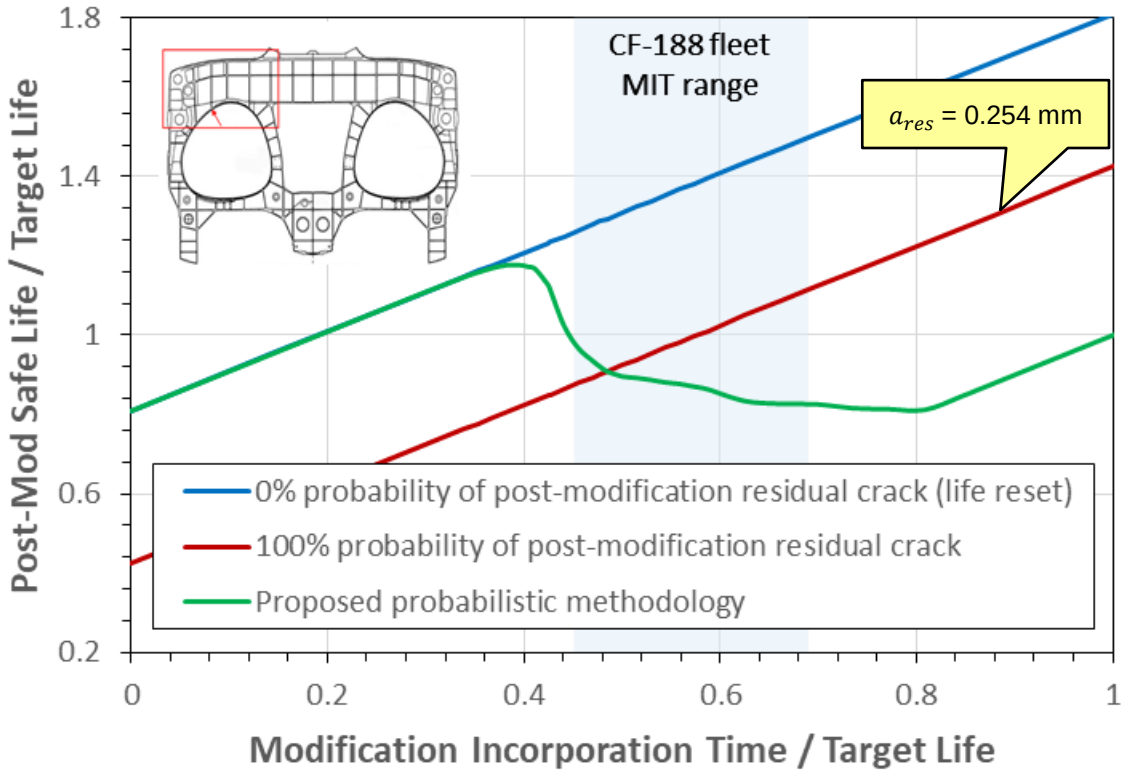
Improvement 2

Actual Crack Size Reduction

- Assumption: POD = 0
- Cracks completely cut → Life Reset (conversion to full CG model)
- Cut cracks → Life from a_{MIT} - a_{cut}
- Post-Mod SLL = Individual MIT + mixture of two populations (life reset + CG)
- Safe Life Limit (SLL): CPOF of 0.001 per A/C

Observation:

- The probability of remaining large post-Mod cracks makes this approach more severe for fleet MIT range

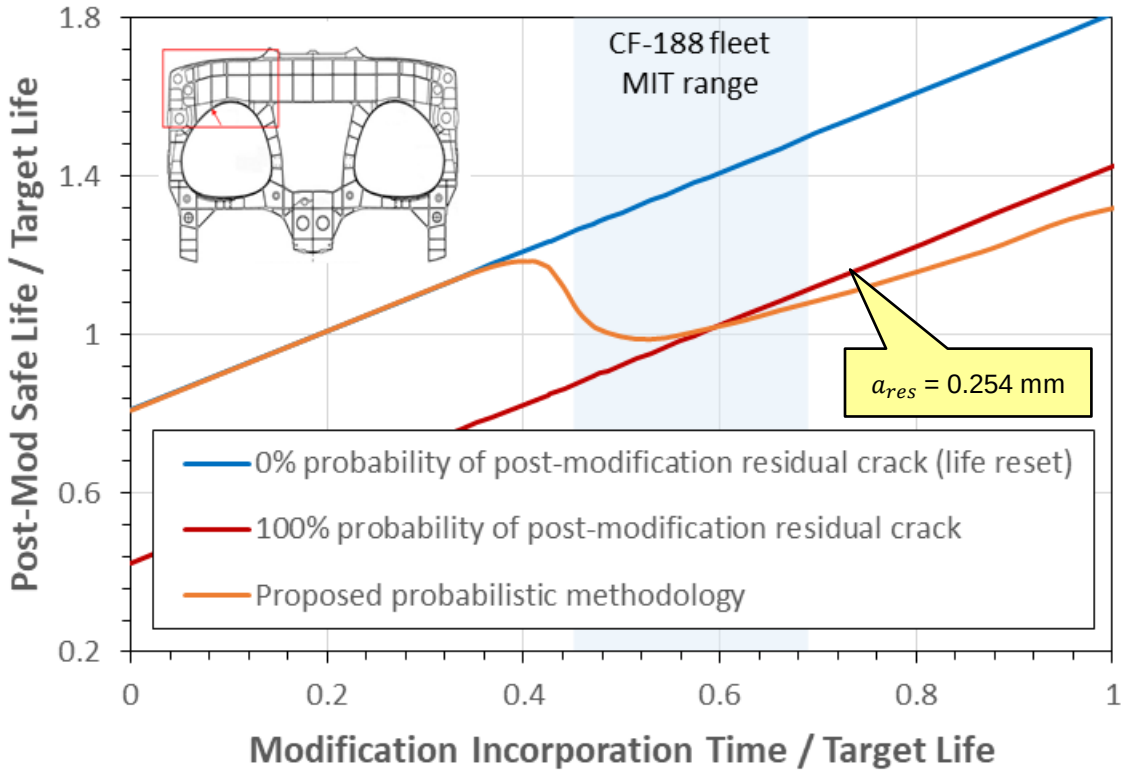


Enhanced 2nd OS Mod Analysis Methodology

Improvement 3

Actual Crack Size Reduction + Probability of Crack Detection

- Assumption: POD curve from EN-SB-08-012
  - Curve estimated from a_{50} and a_{90}
- Cracks completely cut → Life Reset (conversion to full CG model)
- Cut cracks → Life from a_{MIT} - a_{cut}
- Post-Mod SLL = Individual MIT + mixture of two populations (life reset + CG)
- Safe Life Limit (SLL): CPOF of 0.001 per A/C



Observation:

- For the fleet MIT range, all post-Mod cracks lead to a life longer than the target life

CONCLUSION

Probabilistic Lifing of a Second Oversize Hole Modification

Conclusion

- Within the context of a Safe Life approach, The proposed probabilistic methodology removes conservatism associated with the current post-Mod lifing guidelines
- Simplified approach: must be used with caution (POD assumption, MIT)
  - Was used fleet-wide (average MIT), with additional conservative assumptions, to make the ALEX Modification 6.0 on LLI 855 reach the Target Life
- Enhanced approach: more probabilistic and less conservative
  - A/C-specific implementation, representative residual damage size distribution, POD curve based on most recent USAF data, contribution from entire crack population
- This type of probabilistic approach can be valuable to get extra life for problematic locations of aging fleets, especially near the end of the life

Probabilistic Lifing of a Second Oversize Hole Modification

Acknowledgement

Défense nationale
National Defence

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THANK YOU

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