FAA Data Evaluation

Bob Eastin – CSTA for Fatigue and Damage Tolerance

Al Broz- CSTA for Non Destructive Inspection

Overview

- Fatigue
- Fatigue Management
- Cessna 400 Wing Spar Cap Findings
- Inspection Considerations
- Wing Structural Integrity Issues
- Proposed Corrective Action

Fatigue

"The process of *progressive localized* permanent structural change occurring in a material subject to conditions which produce fluctuating stresses and strains at some point or points and which may cumulate in *cracks* or complete *fracture* after a sufficient number of fluctuations."

ASTM E206-72

Fatigue

- Many structures are susceptible.
- Significant threat for aerospace structures.
- For susceptible structures the question is not if it will occur but when it will occur.
- It can't be stopped but it can be managed.

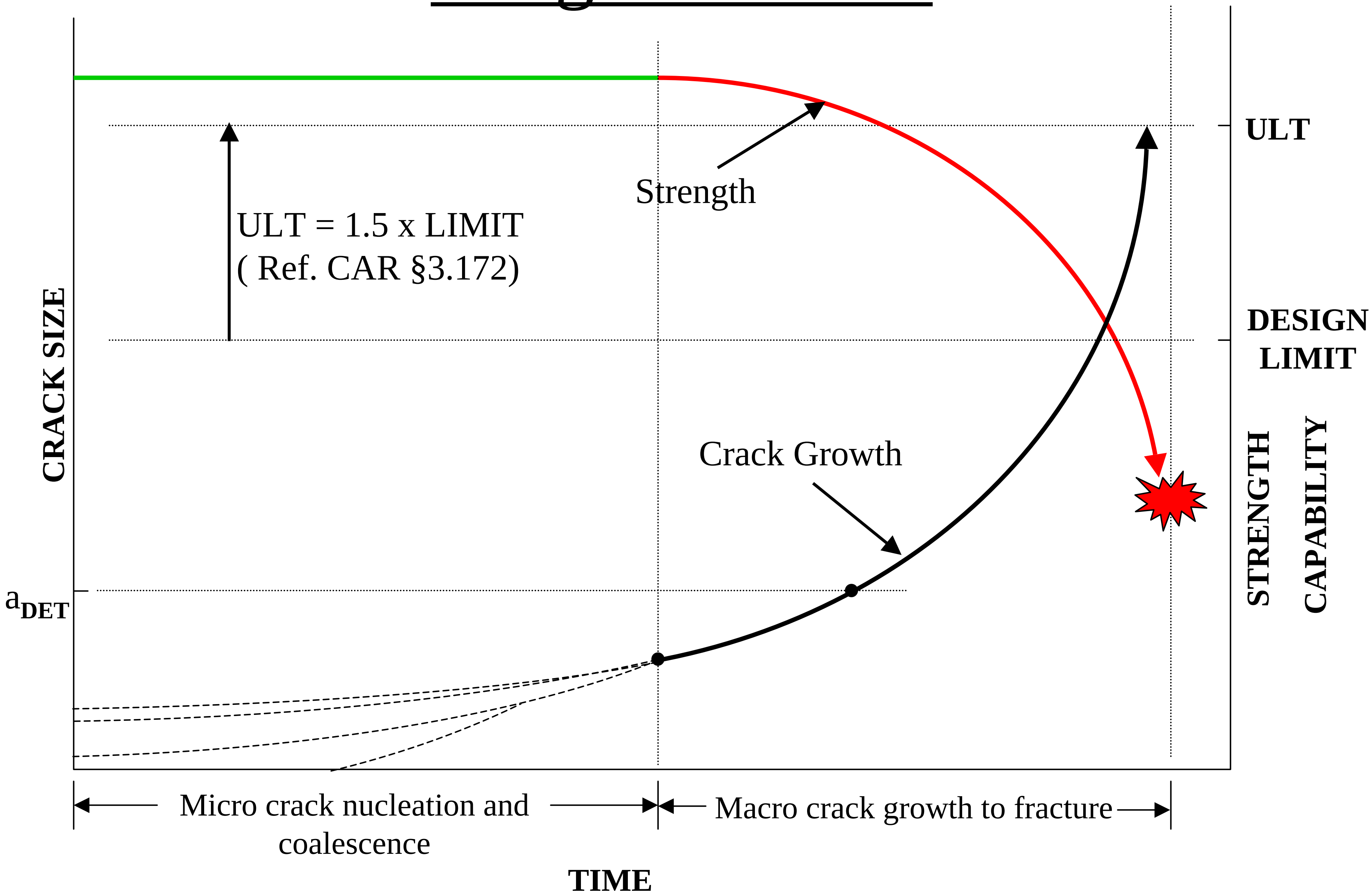
CAR §3.173, Strength and Deformation

- Defines required static strength:
  - Support limit loads without detrimental or permanent deformation.
  - Support ultimate loads without failure.
- Type design requirements.
- Applicable to repair and modification.
- Applied to structure known to be cracked if considering potential operation without repair.
- No provision for relaxation based on age.

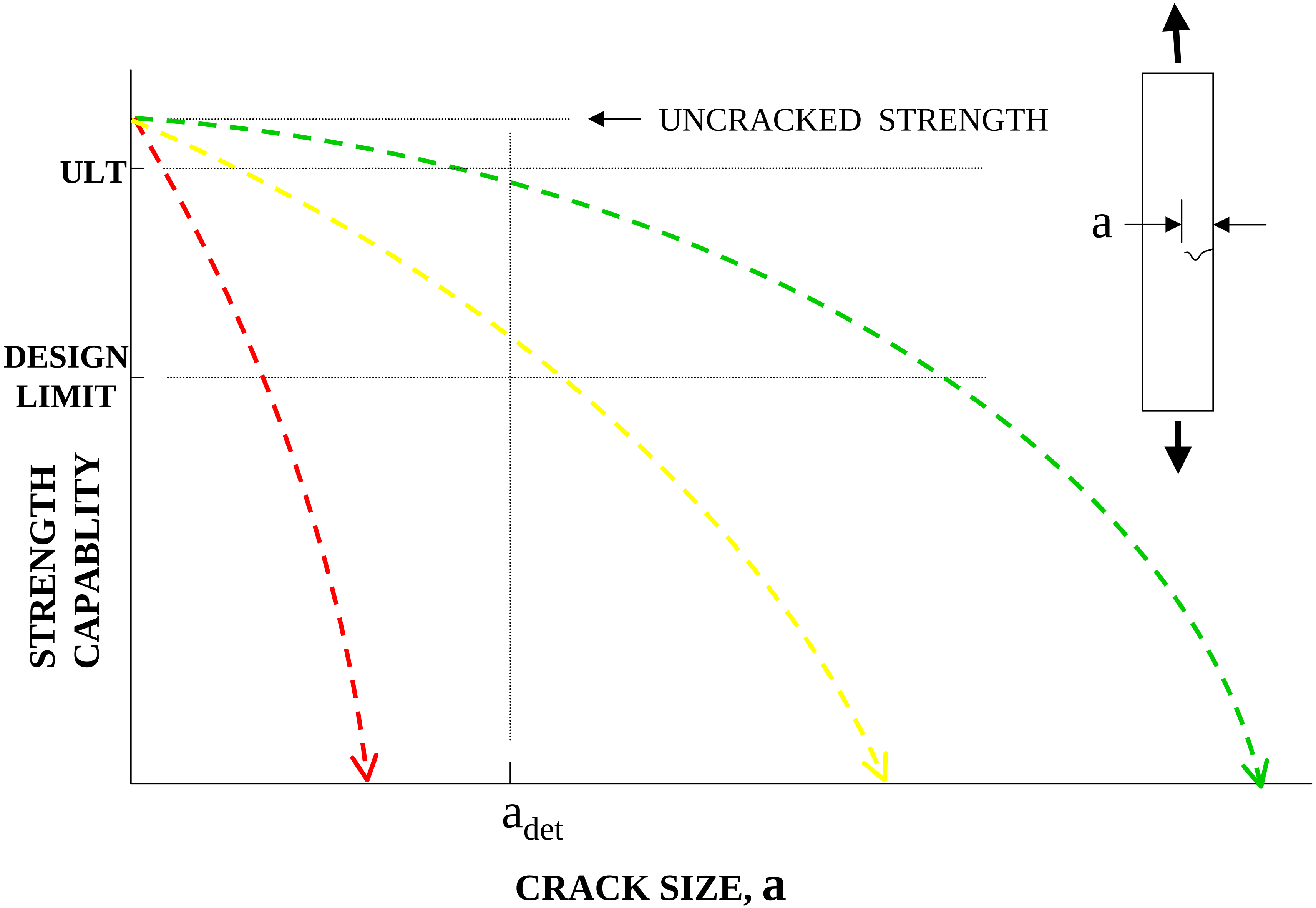
FAR §21.183, Issue of Standard Airworthiness Certificates

- Prerequisites
  - Conformance to type design
  - Condition for safe operation
- Expectation is retention of type design strength

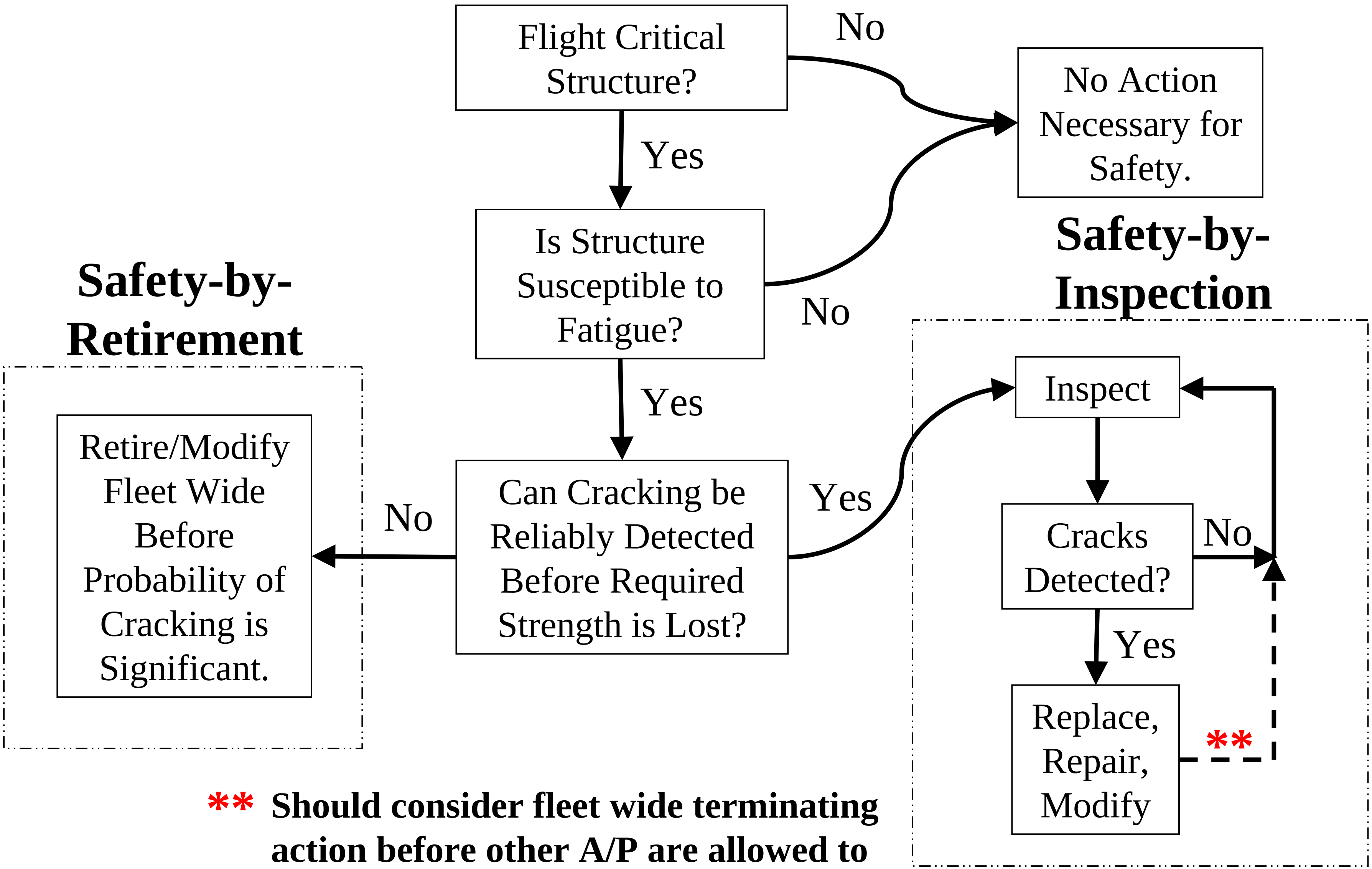
Fatigue Process



Strength vs. Crack Size



Fatigue Management Logic



** **Should consider fleet wide terminating action before other A/P are allowed to crack.**

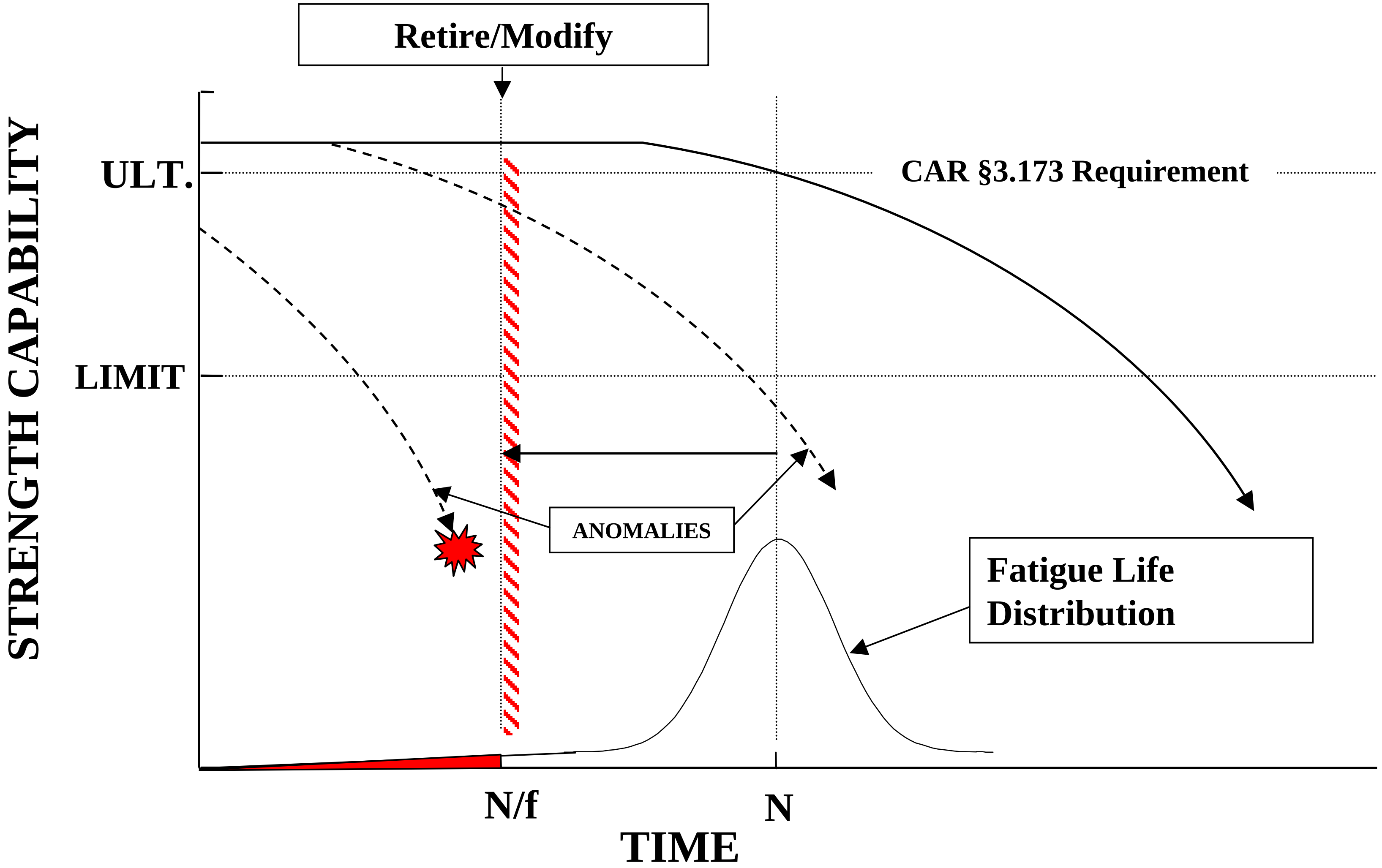
Safety-by-Retirement (SBR)

- "Run and retire".
- Pre-emptive replacement/modification at an established time regardless of condition.
- Typical approach for small airplanes, rotorcraft and engines.
- Success depends on retiring/modifying all parts early enough to address even those of lower fatigue quality.

Safety-by-Retirement (cont’d)

- Vast majority of parts will be retired/modified with life remaining.
- May be used whether or not cracks are detectable before they become critical.
- Only alternative when critical cracks are smaller than detectable.
- Typically does not account for anomalies (e.g. manufacturing defects).

Application of SBR



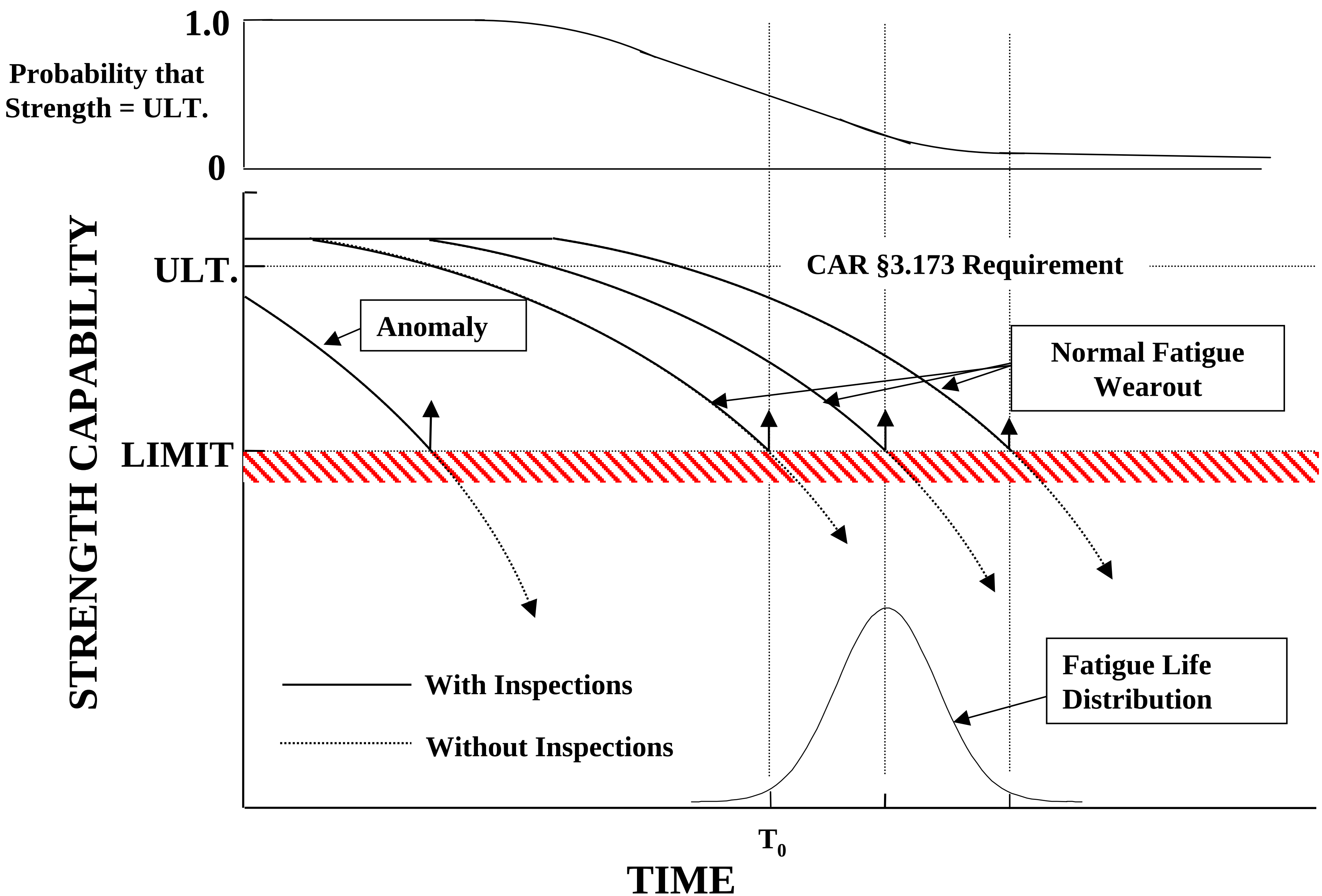
Safety-by-Inspection (SBI)

- “Find and fix”.
- Dedicated inspections at fixed intervals for fatigue cracking.
- Success depends on reliably detecting fatigue cracking before strength capability falls below a specified level.
- Requires evaluation of crack growth and residual strength characteristics.

Safety-by-Inspection (cont'd)

- Can only be used if cracks are detectable before they become critical.
- Can be effective against anomalies (e.g. manufacturing defects).
- Highly dependent on reliability of inspection system/process.

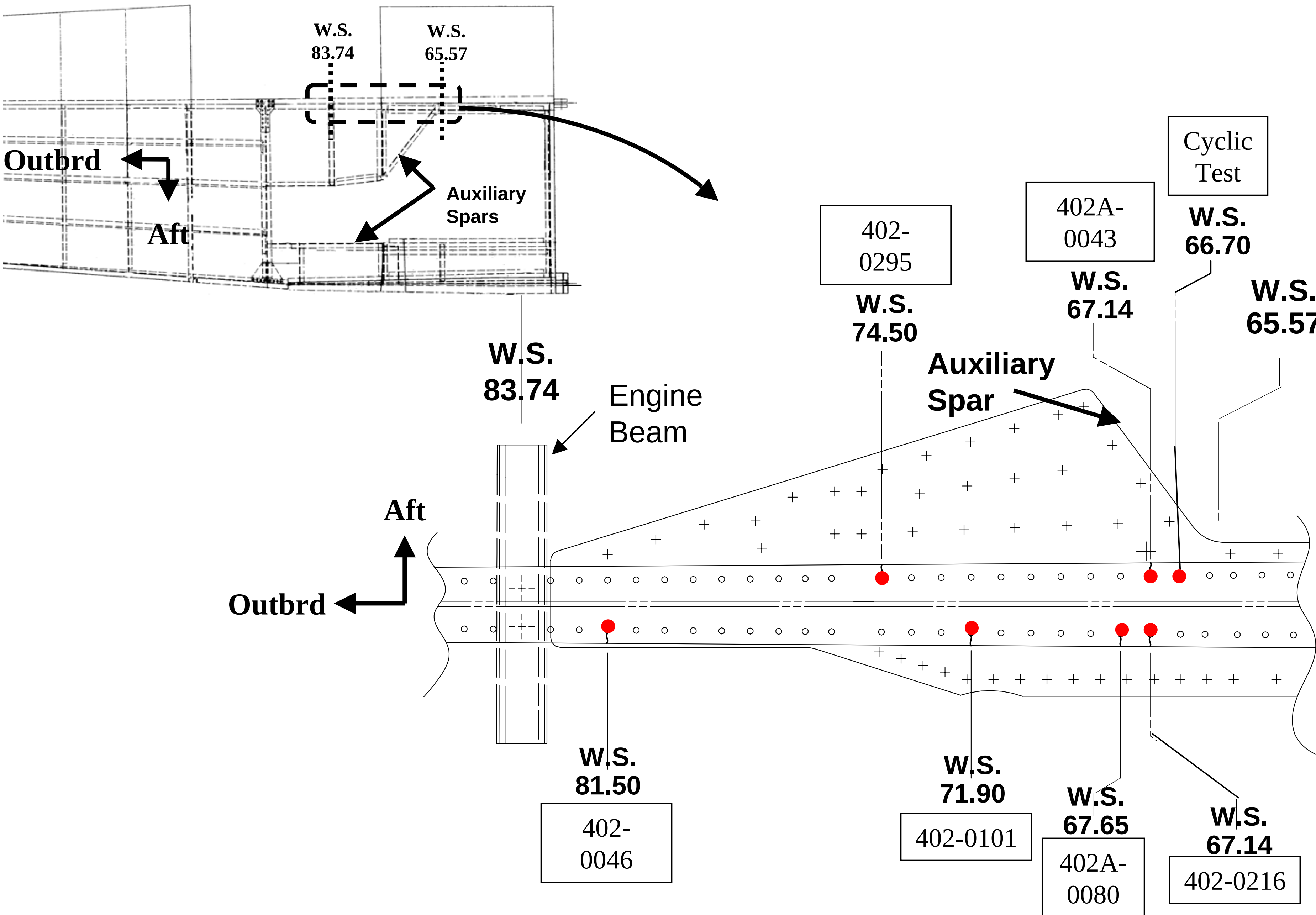
Safety-by-Inspection



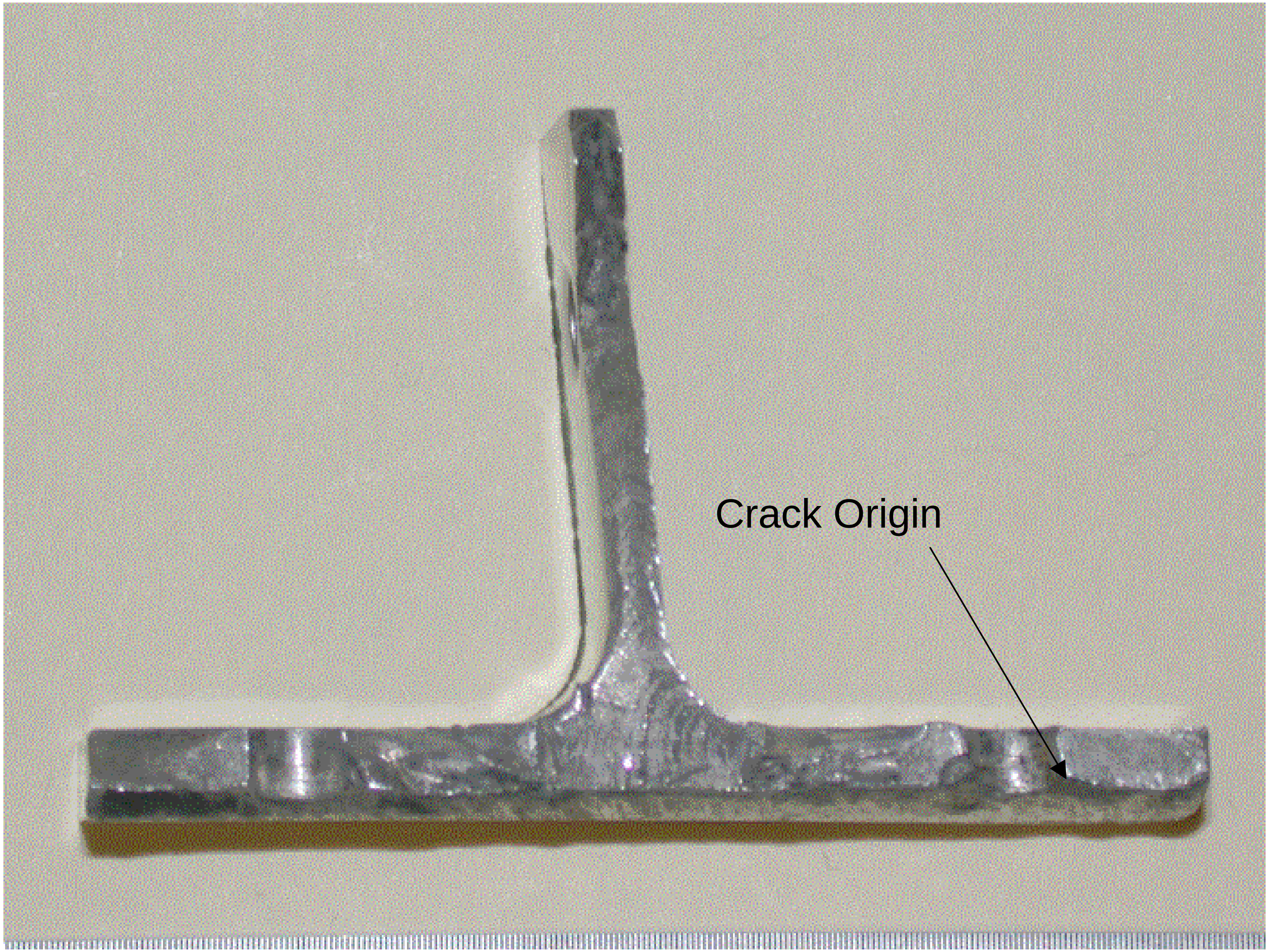
402 Fatigue Cracking Experience

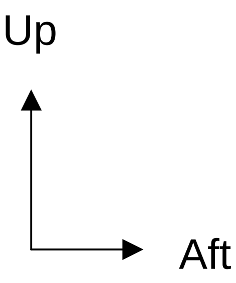
A/P Serial No.	Flight Hours	Wing Station	Location	Crack Origin	Failure Mode
402-0046	8373	81.50	Fwd Flg	Fastener Hole	Complete cap failure. The airplane had an engine fire that left the cap with 50% of required tension capability after 1830 hours. – Right Wing
402-0295	8057	74.50	Aft Flg	Fastener Hole	Complete cap failure – Left Wing
402A-0043	13824	67.14	Aft Flg	Fastener Hole	.05” crack detected when evaluating new NDI equipment.
402-0101	16000	71.90	Fwd Flg	Fastener Hole	Complete cap failure – Left Wing
402A-0080	13773	67.65	Fwd Flg	Fastener Hole	Complete cap failure – Left Wing
402-0216	9012	67.14	Fwd Flg	Fastener Hole	Spar cap ligament failure – Left Wing
Cyclic Test	14,000	66.70	Aft Flg	Fastener Hole	Complete cap failure.

402 Known Cracking Locations

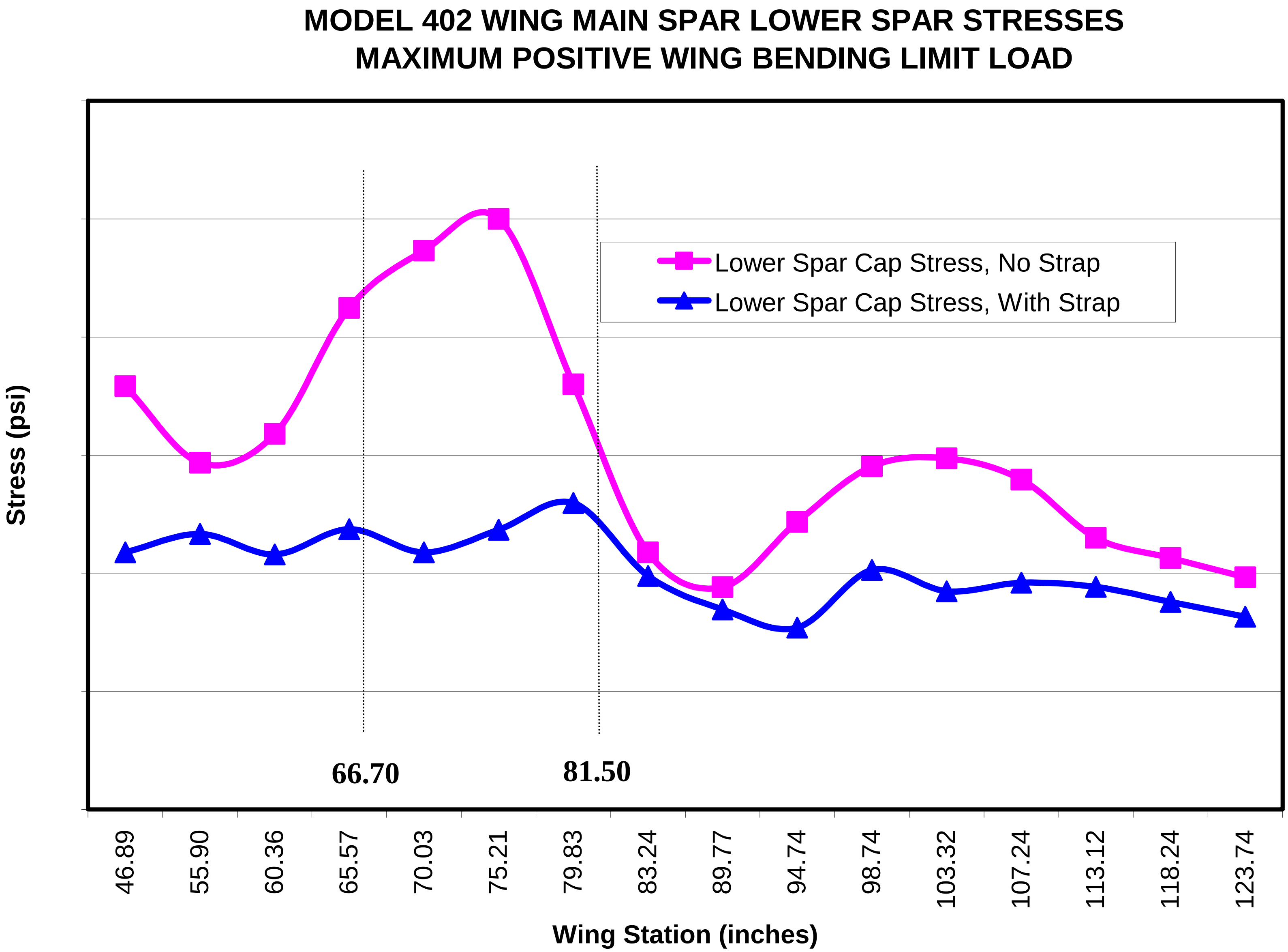


402-0295 Fracture Face
W.S. 74.50, @8057 Hours





402A0080 Fracture Face
W.S. 67.65 @13,773 Hours

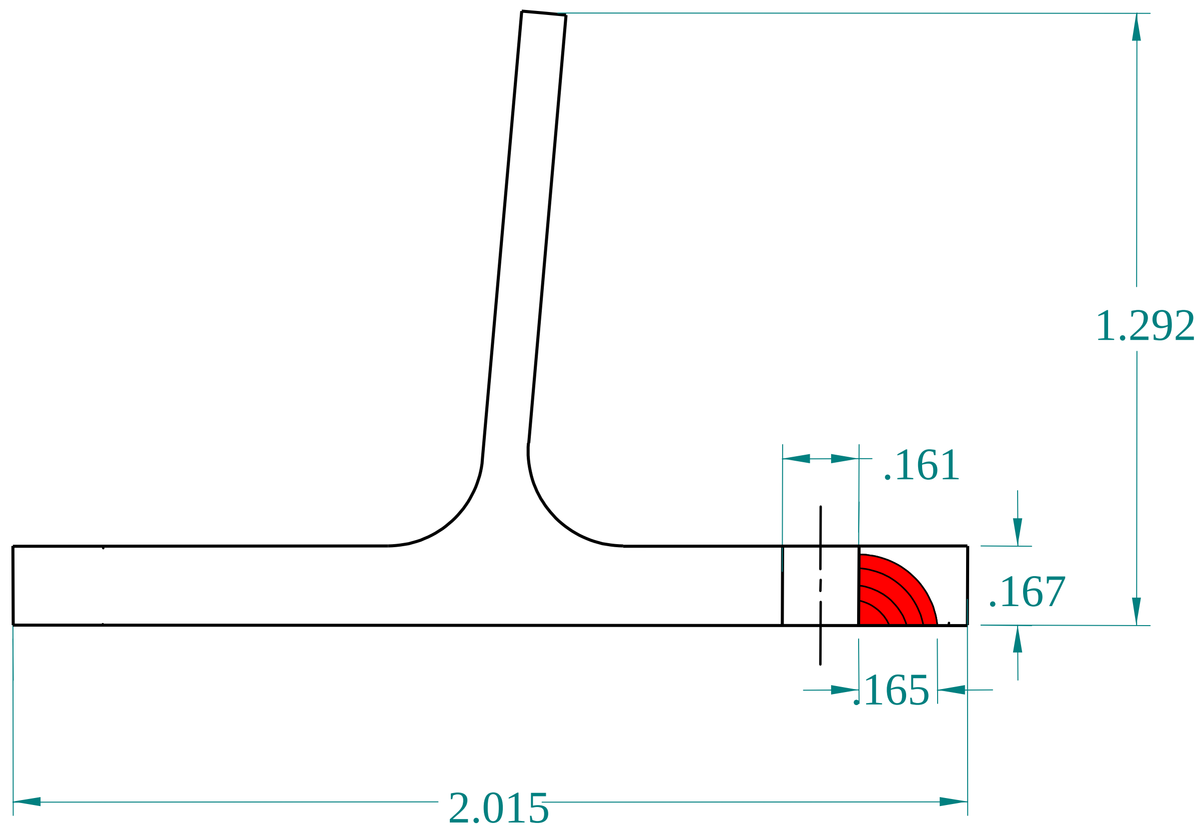

MODEL 402 WING MAIN SPAR LOWER SPAR STRESSES
MAXIMUM POSITIVE WING BENDING LIMIT LOAD
Stress (psi)
Lower Spar Cap Stress, No Strap
Lower Spar Cap Stress, With Strap
66.70
81.50
46.89
55.90
60.36
65.57
70.03
75.21
79.83
83.24
89.77
94.74
98.74
103.32
107.24
113.12
118.24
123.74
Wing Station (inches)

Damage Tolerance Assessment Results

- 401, 402, 411 and 414A(1-200) wing strength with spar cap failed is less than **1/2** original type design ultimate strength.
- 402C and 414A(201-) wing strength with spar cap failed is just equal to **2/3** original type design ultimate strength.
- *With spar cap failed all models have lost type design strength margin of 1.5.*

402 Spar Cap Critical Crack Size

(i.e. results in complete cap failure at 2/3 ultimate)



NDE CAPABITITY FOR

DETECTING FATIGUE CRACKS

IN SPAR CAP

Al Broz

- SAFE INSPECTION PERIOD

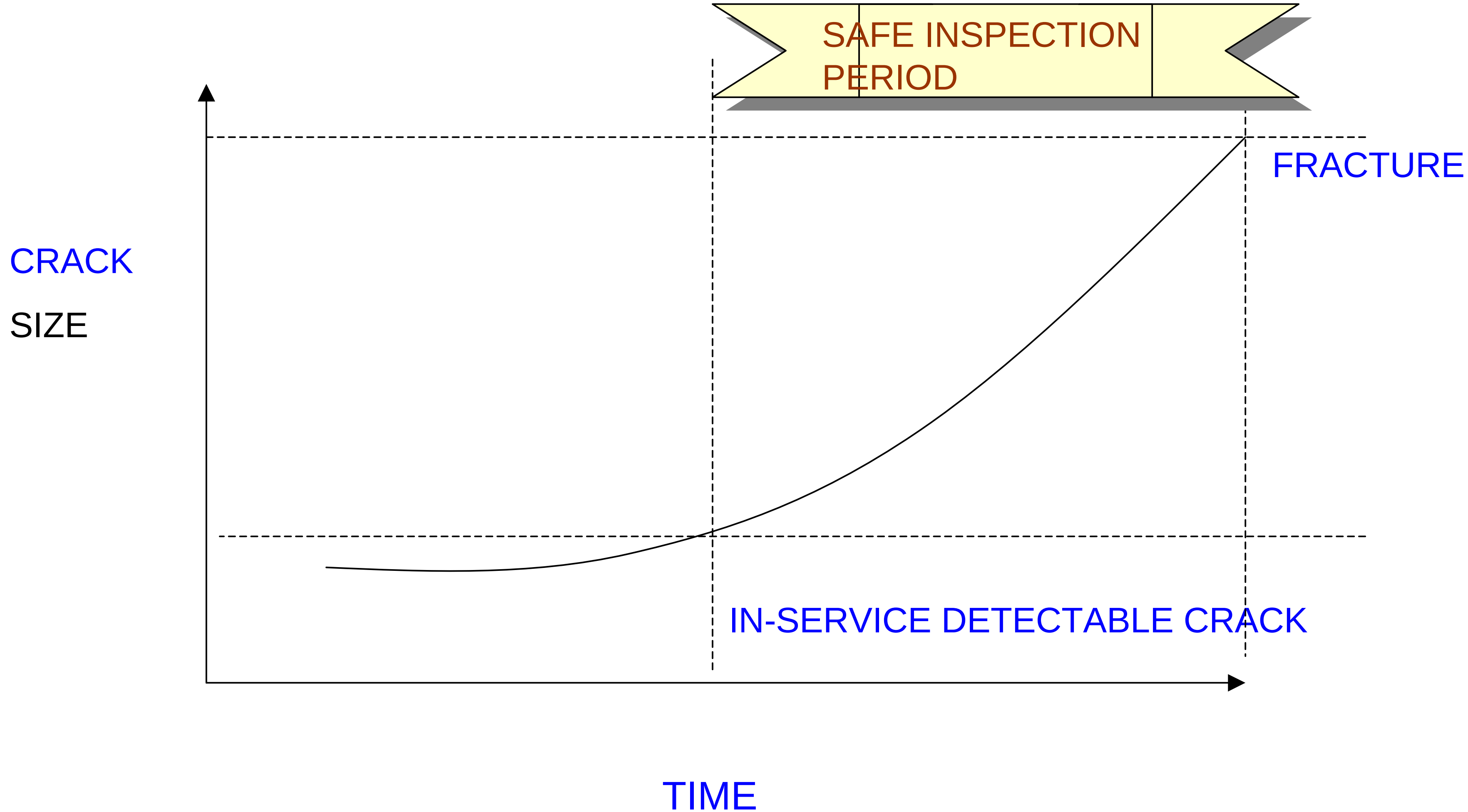
  Time for an in service detectable crack to grow to failure at limit load

- IN SERVICE DETECTABLE 0.19” CRACK

- CRITICAL/FAILURE CRACK 0.16”

- THERE IS NO SAFE INSPECTION PERIOD

SAFE INSPECTION PERIOD



FREQUENCY OF REPEATED INSPECTIONS

ENSURES THAT NO CRACKS AT OR BELOW THE NDE THRESHOLD CAN GROW TO FRACTURE BEFORE THE NEXT INSPECTION OPPORTUNITY

- WHERE DOES THE CRITICAL/FAILURE CRACK SIZE COME FROM?

  DAMAGE TOLERANCE (DT)

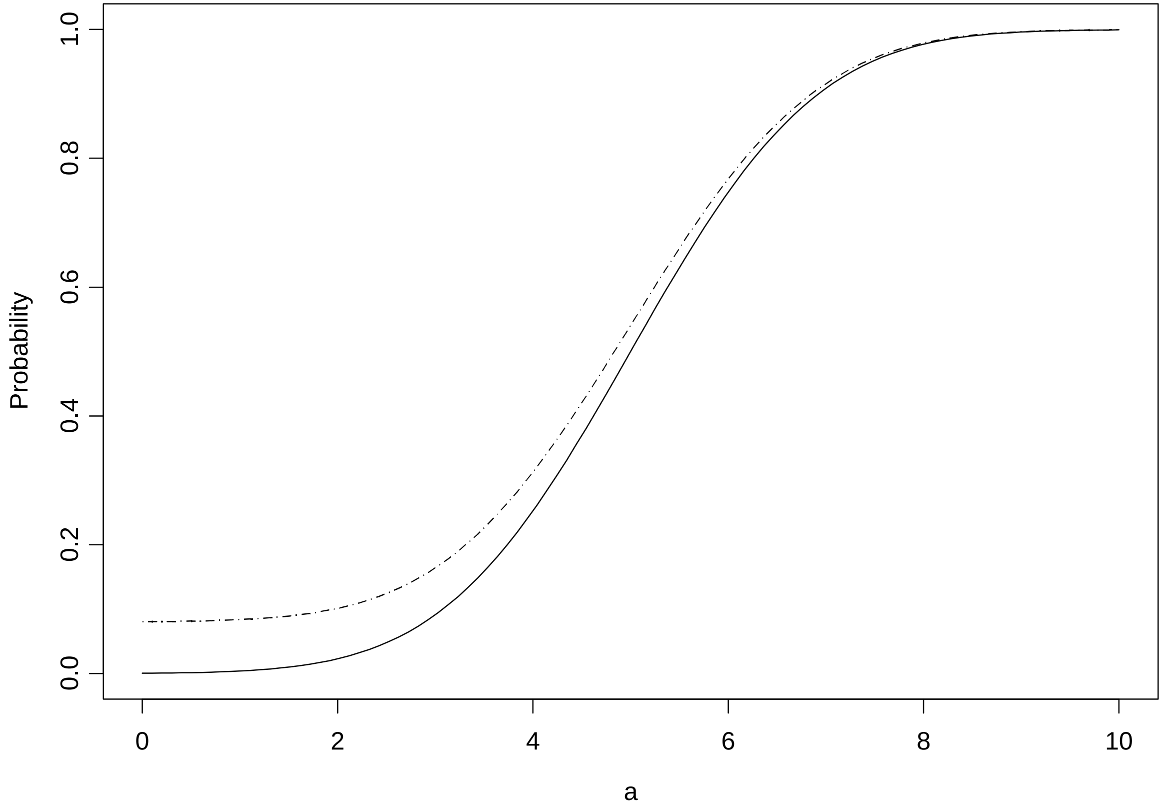
- WHERE DOES THE “RELIABLY DETECTABLE” IN-SERVICE CRACK SIZE COME FROM?

  PROBABILITY OF DETECTION (POD)

  RELIABLY DETECTABLE FLAW

What is POD?

- POD is a statistical measure of the detection of a defect that is present
- Data is usually presented as a probability graph versus indication size (crack, FBH, etc.)

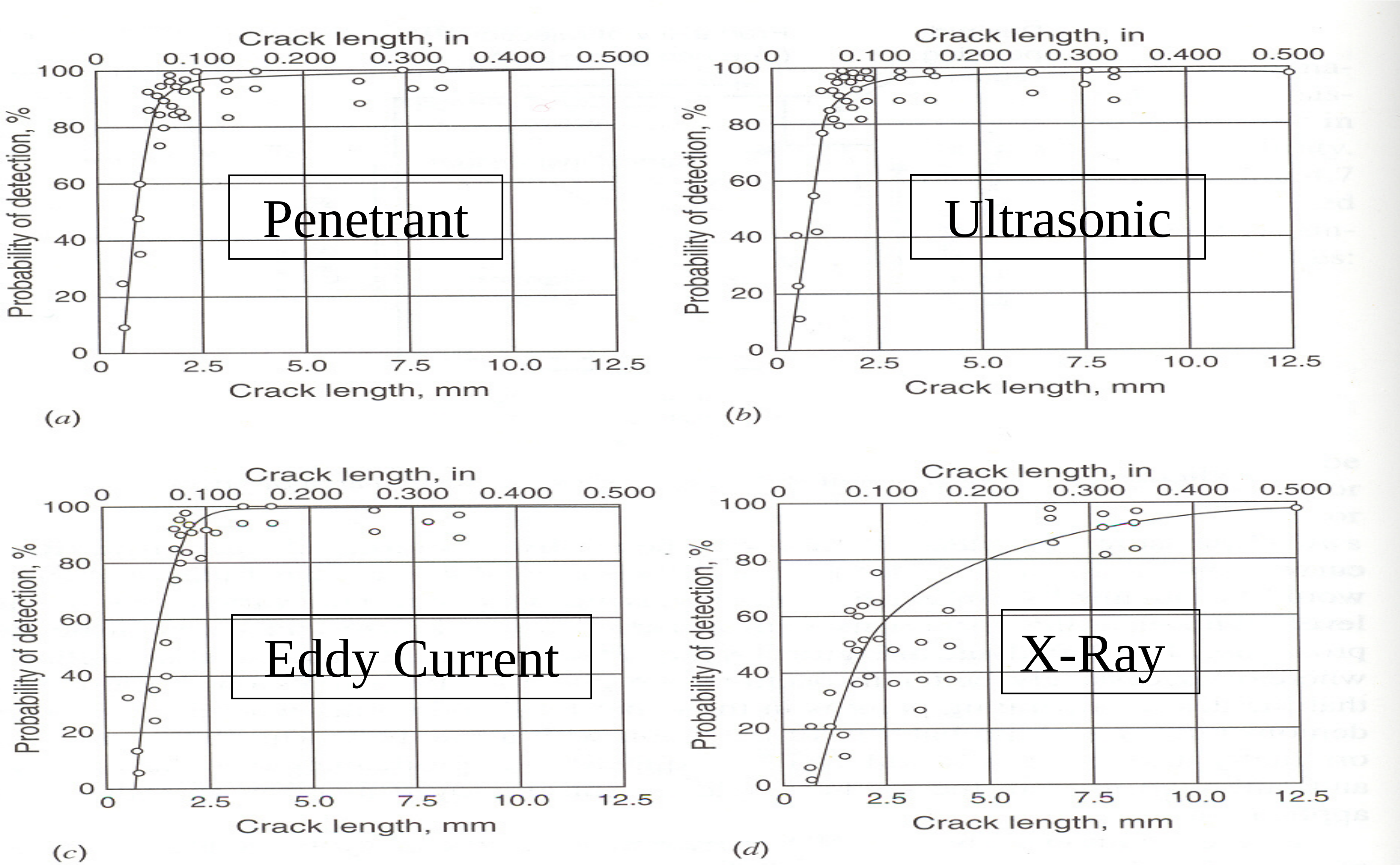


POD - probability that a defect with specific properties will be detected, under specific inspection conditions, given that there is such a defect in the material scanned

WHAT DOES POD TELL US?

- Determines size of defects the method is capable of finding
- Indicates proportion of defects that are detected
- Compares performance of system, inspector, technique, etc.
- Allows comparison of two or more methods

Comparison for Surface Breaking Fatigue Cracks



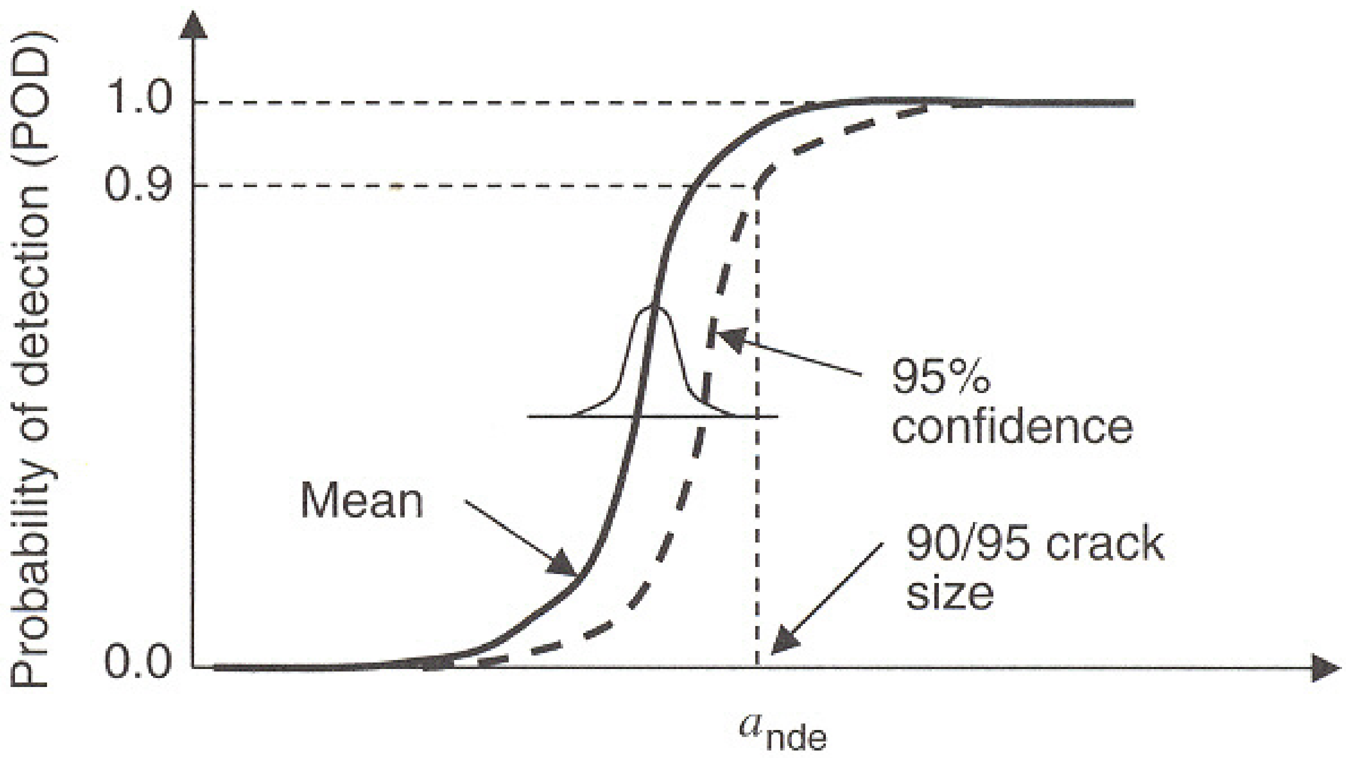
Ref. W.D. Rummel, G.L.Hardy, T.D. Cooper, "Applications of NDE reliability to Systems," in ASM Handbook, Vol. 17: Nondestructive Evaluation and Quality Control, ASM International, Materials Park, Ohio, 1989, pp. 674-688.

Many Ways to Determine POD

“Best" Reference is:

W. D. Rummel and G.A. Matzkanin, Nondestructive Evaluation (NDE) Capabilities Data Book. Nondestructive Testing Information Analysis Center (NTIAC), Texas Research Institute Austin, Texas.

90/95



Crack Size (a)

90/95

Given 100 inspectors

95 will find the crack

90% of the time

THE 0.19” DETECTABLE CRACK SIZE IS OPTIMISTIC

My own recommendation for a detectable flaw size in this situation, and that I would recommend as being acceptable, without additional validation, assuming: good procedure, no corrosion, qualified personnel, and all inspection parameters correctly chosen, would range from 0.2" to 0.3". There is no data that I am aware of that exactly matches this particular situation. One of the resources that I would use is in "Recommendations for Regulatory Action to Prevent Widespread Fatigue Damage in the commercial Airplane Fleet, March 11, 1999, report of the Airworthiness Assurance Working Group for The Aviation Rulemaking Advisory Committee, Transport Aircraft and Engine Issues".

Summary of Findings

- Sufficient service and test experience and fatigue analysis results exist to indicate that:
  - Spar cap is susceptible to fatigue cracking in a local area.
  - Without intervention fatigue cracking can be expected to occur.

Summary of Findings

- Sufficient fracture mechanics analysis results exist to indicate that:
  - The crack size that would cause the cap to fail if design limit load is experienced is relatively small.
- Sufficient NDE data exist to indicate that:
  - Reliable detection of a crack before it reaches critical size may not be possible in some areas.

Summary of Findings

- Sufficient analysis and test results exist to indicate that:
  - With the spar cap failed the wing strength capability is reduced to less than 2/3 of original type design ultimate strength (i.e. all type design strength margin is lost).

Corrective Action Required

- Address the local fatigue critical area at some point in time
  - Retirement/modification required since inspection does not have high enough reliability
- Address the general lack of tolerance to damage
  - Modify design to increase tolerance

Proposed AD Modification

- In effect retires fatigue critical area since working stresses are reduced by up to 50%.
- Significantly increases the structure's inherent tolerance to damage
  - Wing has ultimate capability with the cap completely failed.
  - Cracks can be reliably detected in strap before type design margin is lost.

Proposed AD Compliance Times

- 402A/B “successes” and “failures” can be used to obtain a modification point associated with a low probability of failure.
- Weibull methods are commonly used to accomplish this.
- Requires knowledge of times when failures occurred and time on successful airplanes.

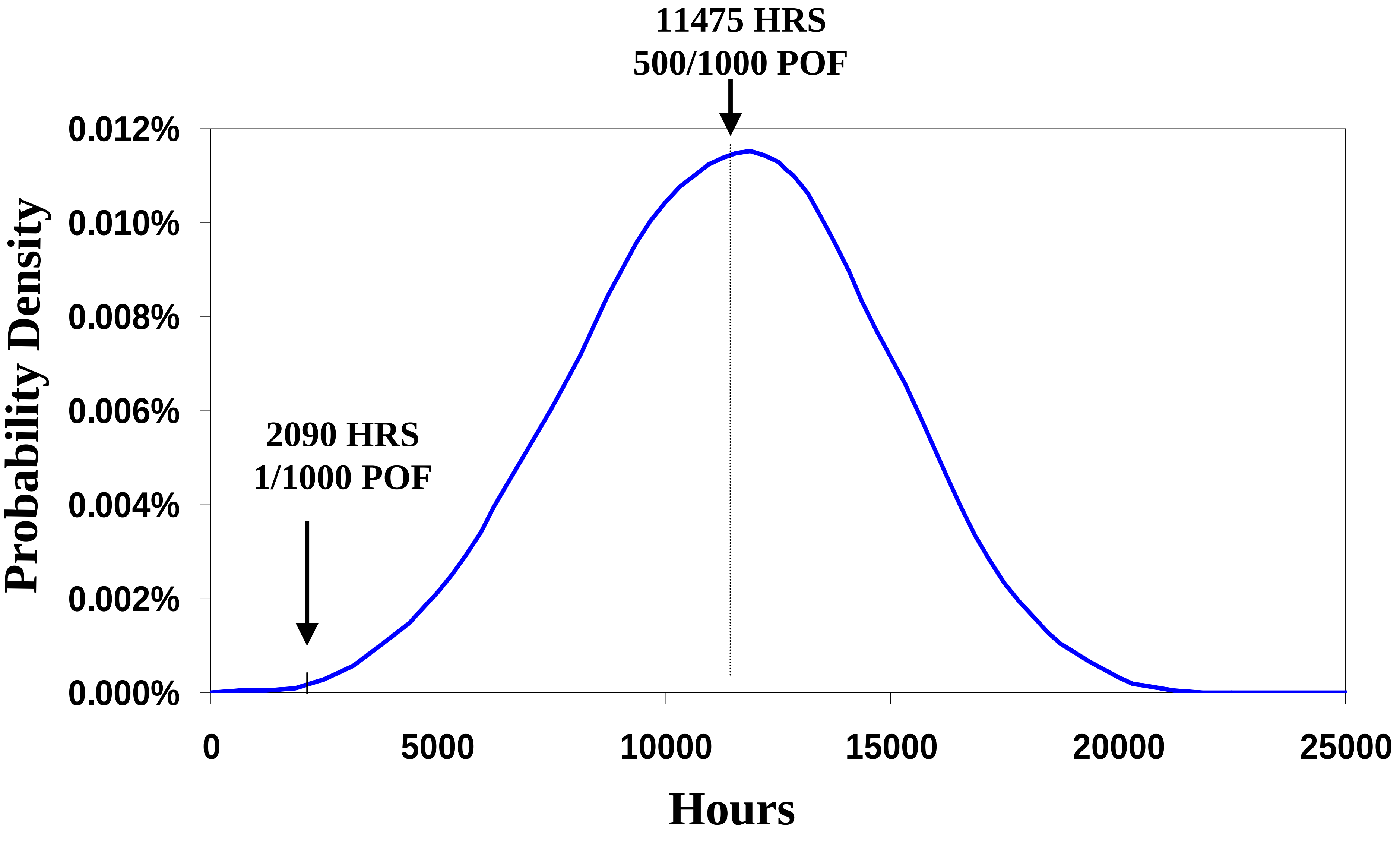
402A/B Fleet Data

- 6 recorded “failures”.
- 109 “successes” with verifiable flight hours.
- 258 “successes” with unknown flight hours.

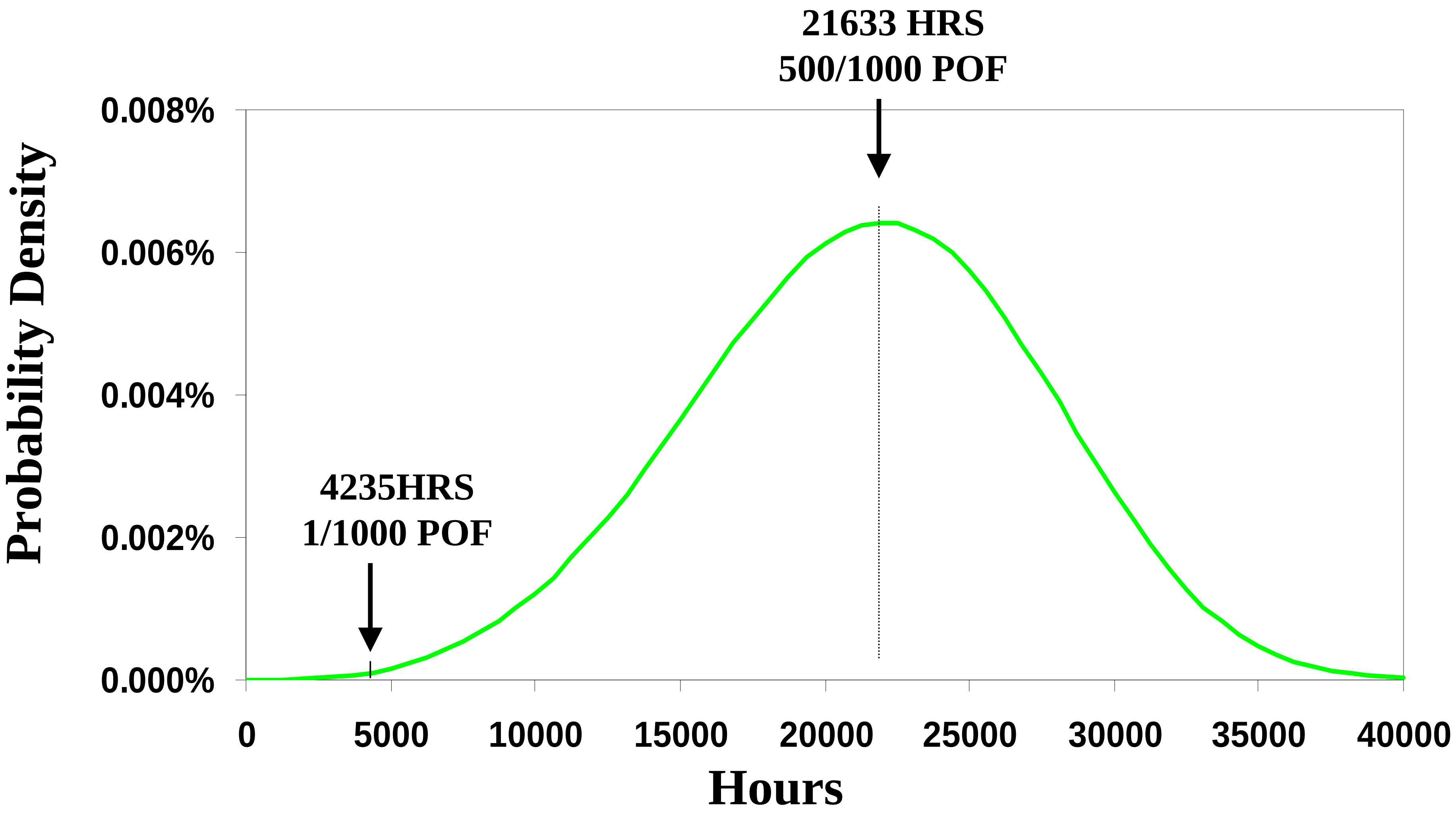
Service Data Analysis

- Weibull method used to develop three different distributions of time to spar cap failure.
  - 6 failures only
  - 6 failures plus 109 successes
  - 6 failures plus 367 successes

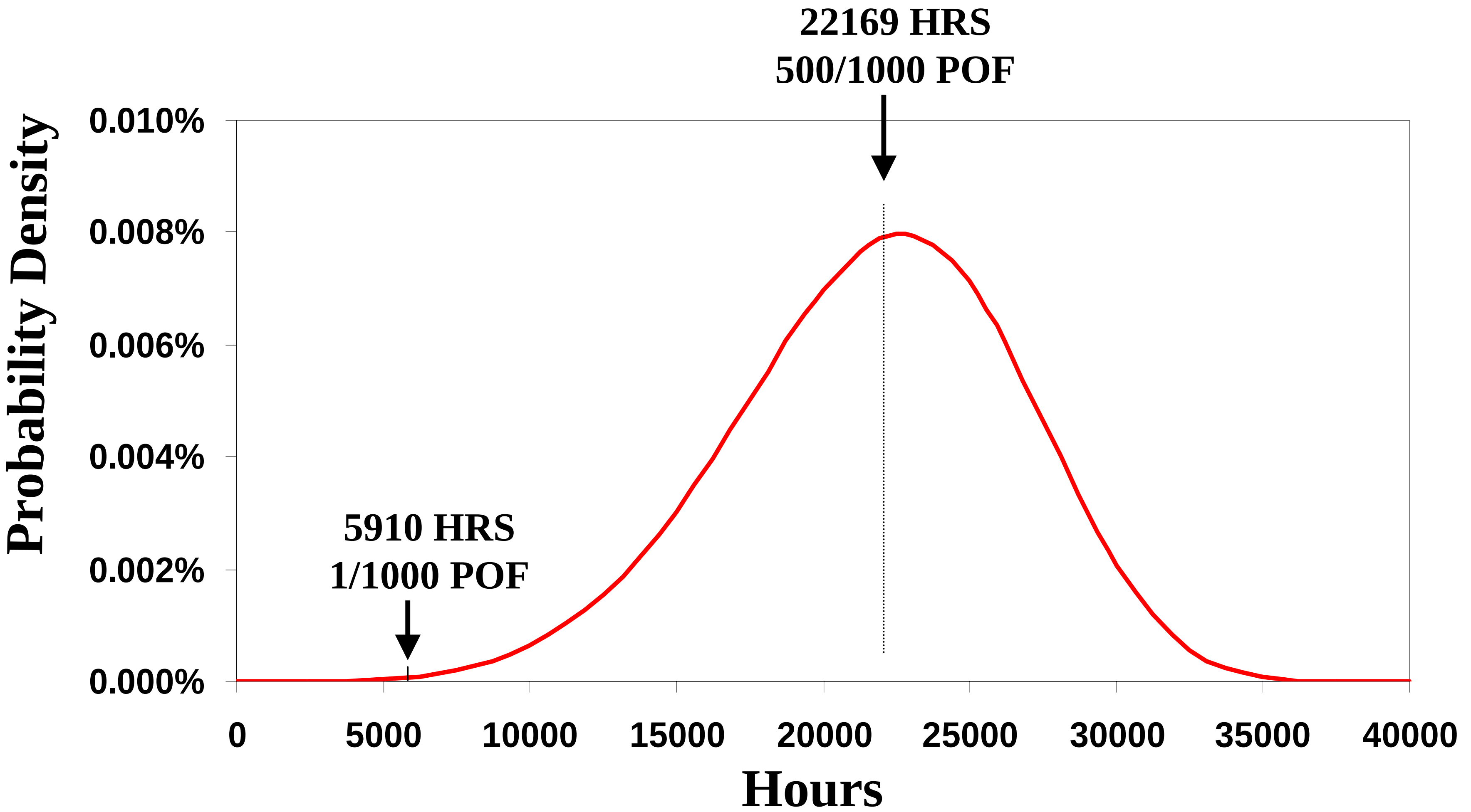
6 "Failure" Distribution



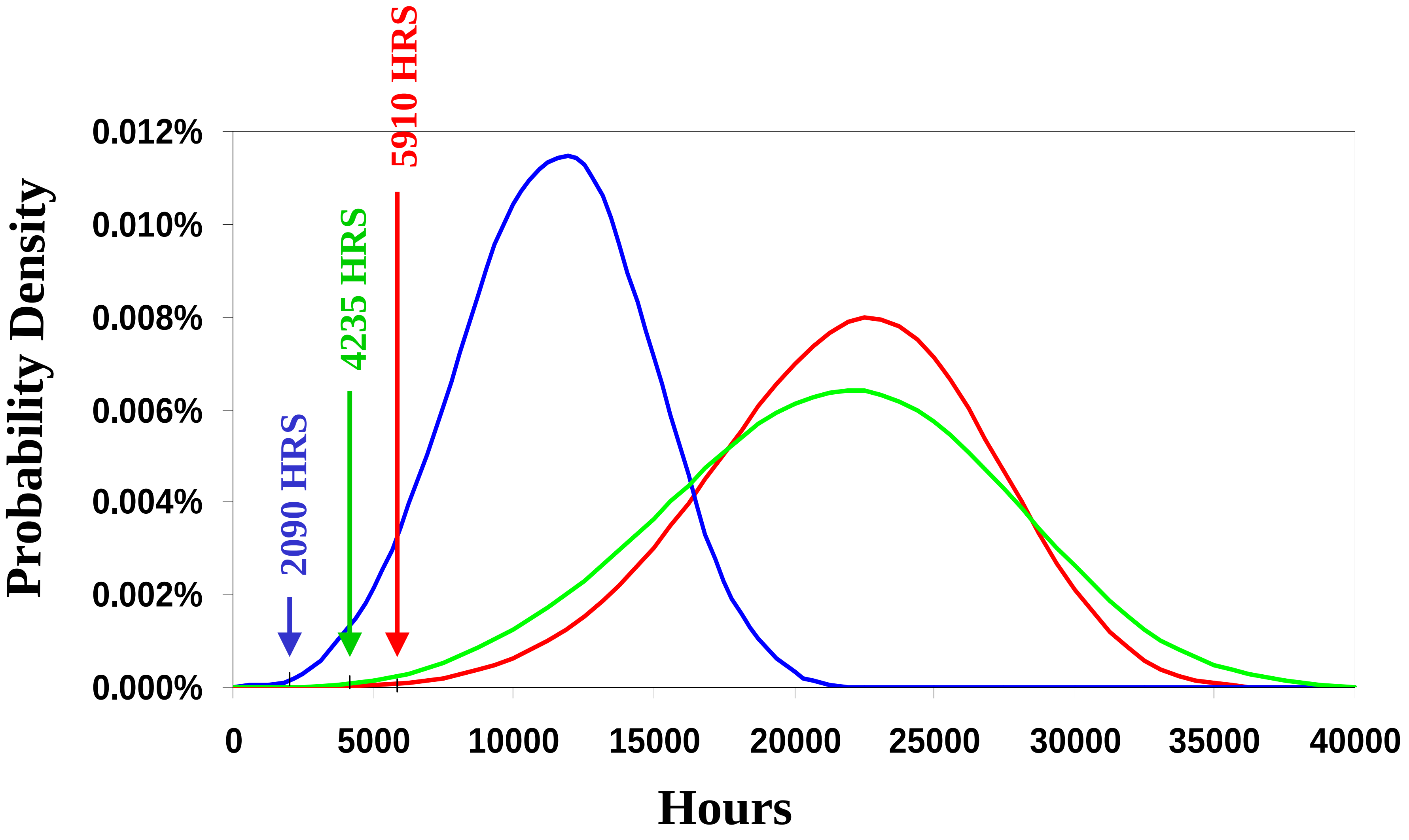
6 + 109 Distribution



6 + 367 Distribution



Distribution Comparison



Conclusions

- Unsafe condition exists in all models
  - 402 test results and service experience
  - Stress analyses
  - Fatigue analyses
  - Damage tolerance analyses
  - Similarity between models

Conclusions (cont'd)

- 2002-CE-05 AD and 2002-CE-57-AD adequately addresses unsafe condition
  - Stress analyses
  - Fatigue analyses
  - Damage tolerance analyses
  - 402 service data evaluation
  - Similarity between models

Conclusions

- Alternative Means of Compliance
  - Must address local cracking
  - Must address inherent lack of tolerance to damage

QUESTIONS?