Nondestructive Inspection Reliability and Risk in the Field and Depot

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Introduction

- This presentation is a review of work performed by the authors for the USAF in late 2005.

- The authors would like to thank
  - UTC
  - AFRL/MLLP, Dr. Malas, Mr. Calzada
  - ASC/EN, Dr. Gallagher, Lt. Col. Butkus

OVERVIEW

- CHARGE: to provide oversight and guidance for:
  - Characterizing what is relevant and what is non-relevant to an NDI miss;
  - Determining what size cracks may be missed when cracks are being detected;
  - Developing a rationale for quantifying risk changes based on NDI misses.

OVERVIEW

- APPROACH
  - Task 1 – Develop the logic for determining the crack sizes that might be missed subsequent to an inspection and recommending approaches to mitigate misses.
  - Task 2 – Compare cracks missed to the damage tolerant design crack growth life behavior.
  - Task 3 – Integrate in-service inspection data into POD evaluation and risk analysis through PROF.

RESULTS

- Our results are summarized in eleven (11) findings, with recommendations.
- Recommendations include both short term and long term actions
- Other teams focused on different elements with primary focus on “human factors”
- Our team did not consider NDI operator “human factors” to be the primary cause for MISSES

Review Of Documents And In Service POD Efforts

- We initially reviewed documents supplied including other team efforts and field NDI data.

- Review included recent
  - “Karta Study of AF Depots”,
  - the original Lockheed “Have Cracks” data for airframes, and
  - the FAA “Reliability Assessment at Airline Inspection Facilities” (ECIRE)

Lockheed – "HAVE CRACKS"

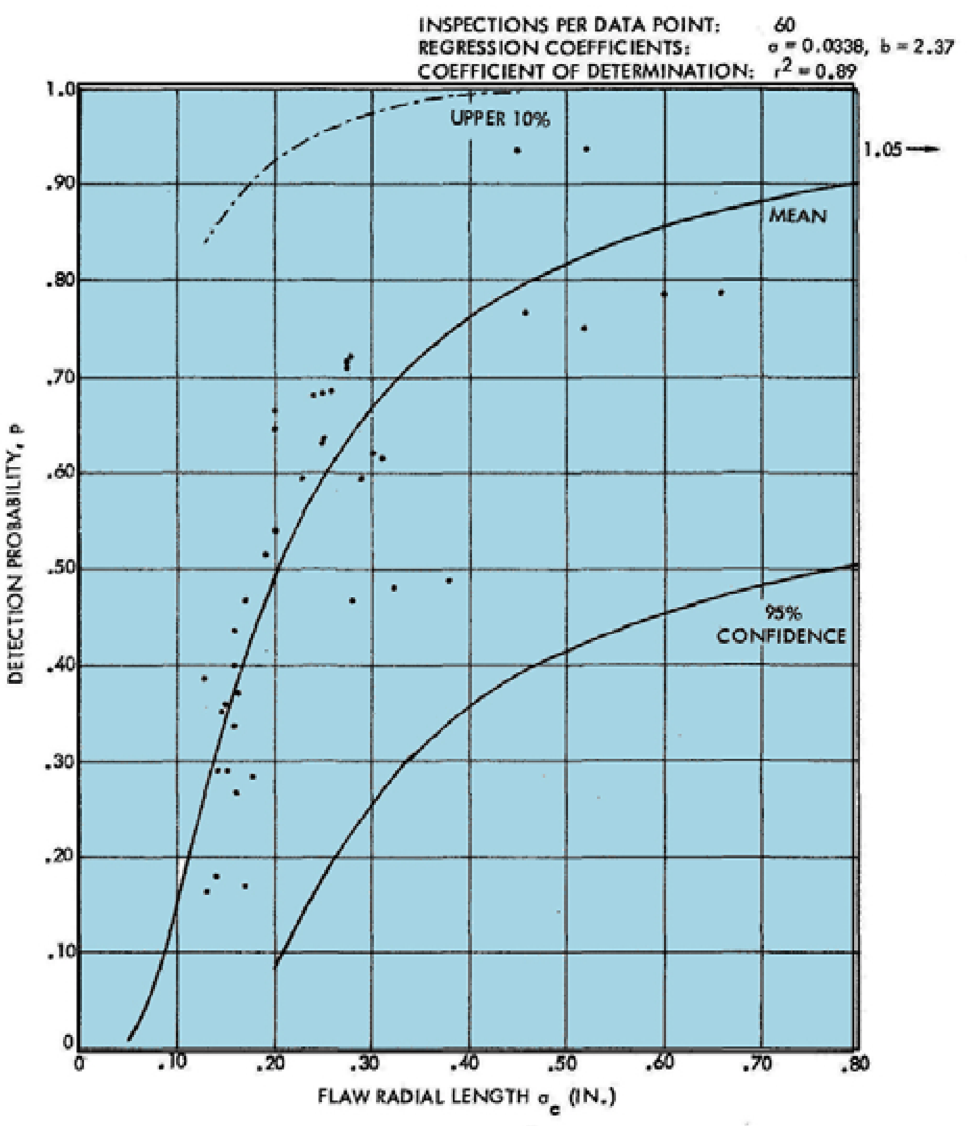
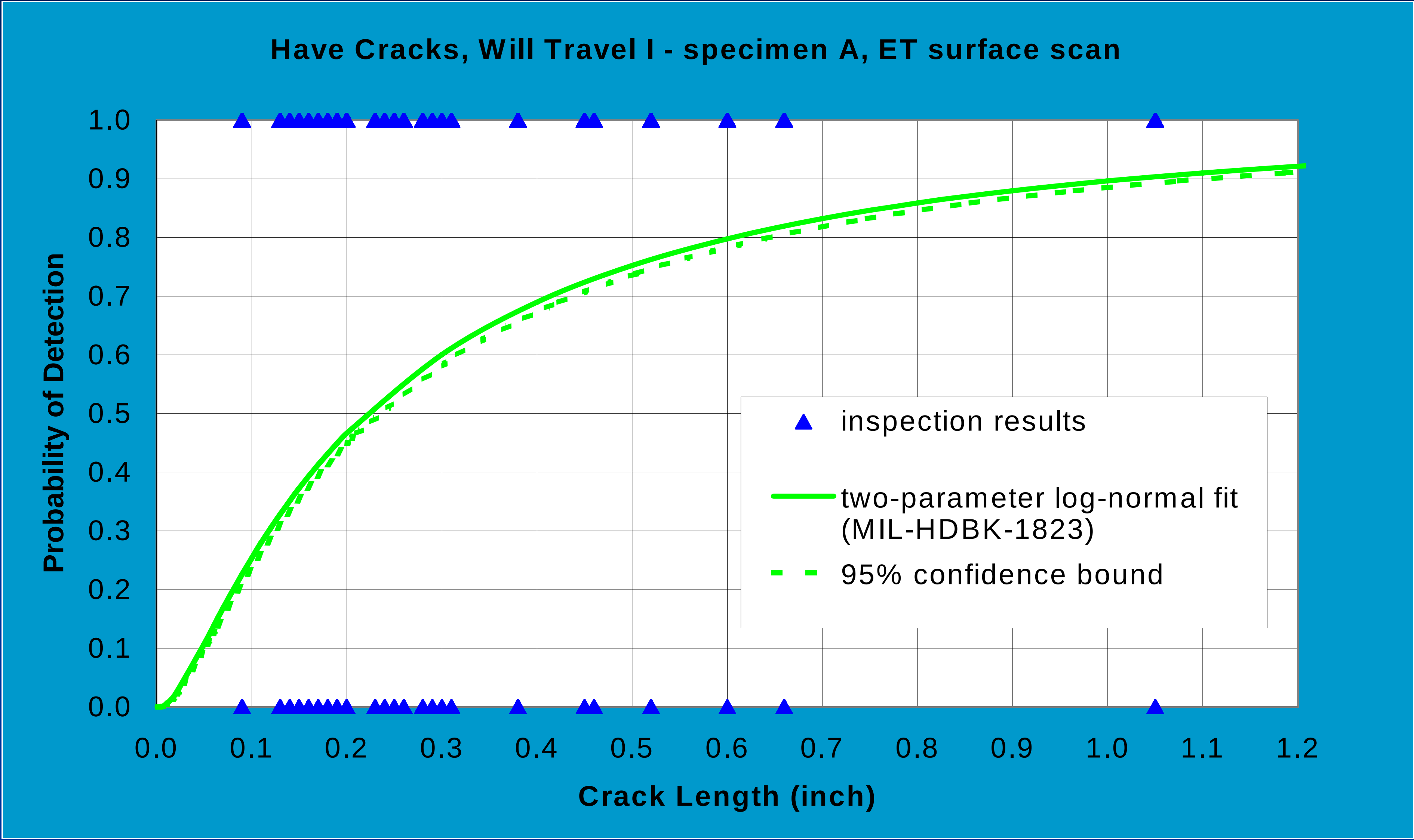


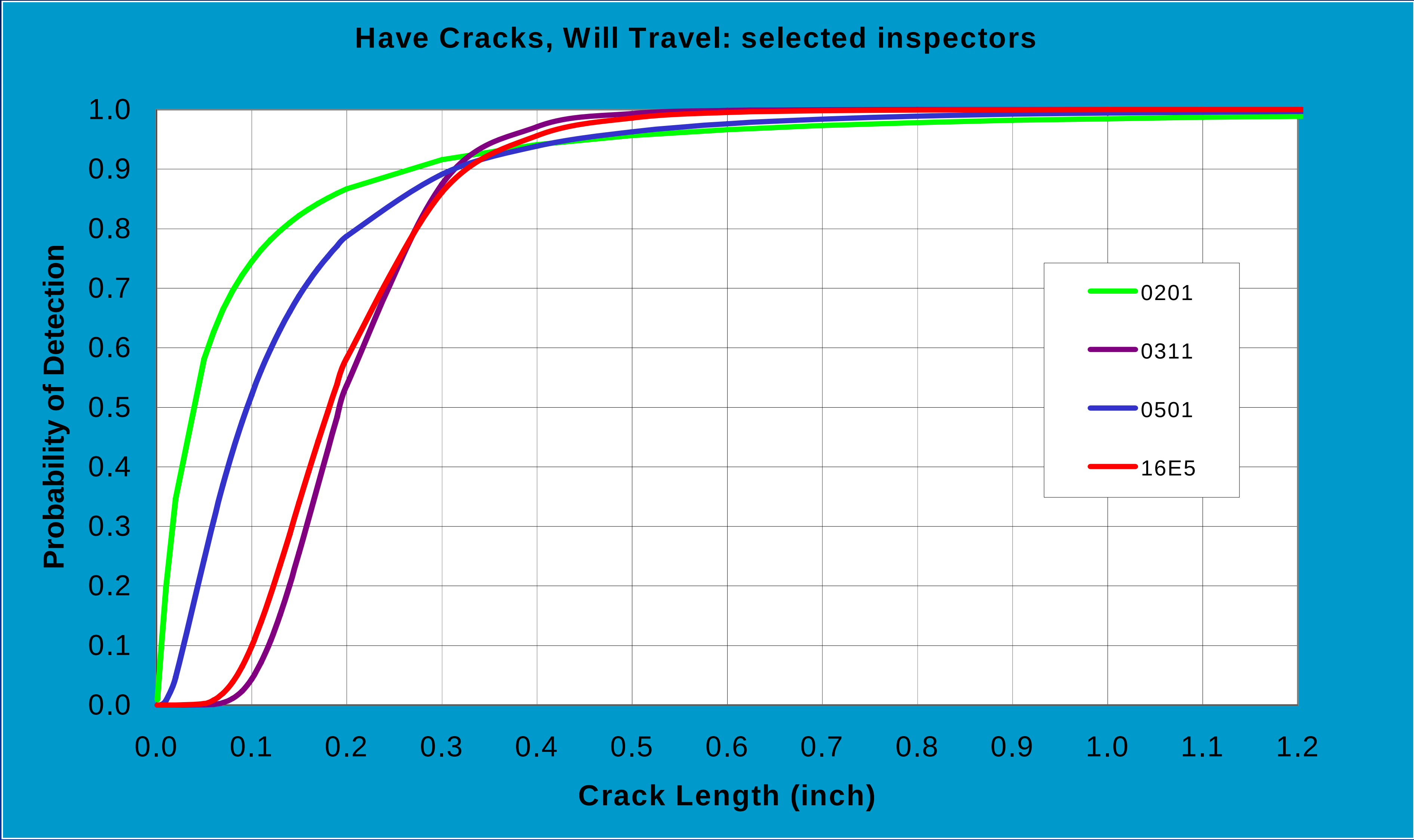
Figure 10-1. Probability of Detection Versus Fatigue Crack Radial Length, Eddy Current Surface Scans Around Countersunk Fasteners, Skin and Stringer Wing Assembly, Sample A.

Reanalysis – “HAVE CRACKS”



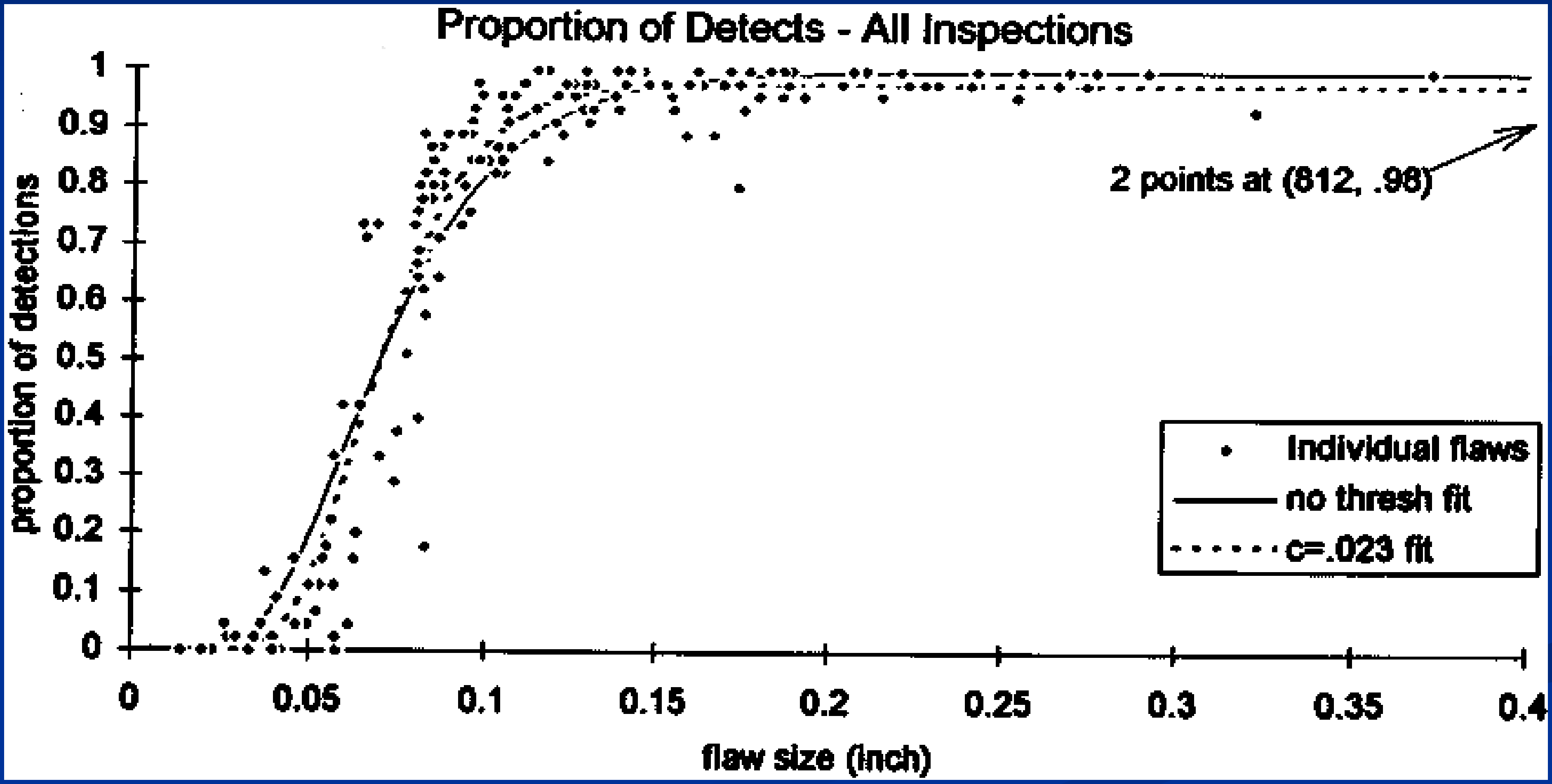
The data, re-analyzed using the MIL-HDBK-1823 method.

“HAVE CRACKS” - selected results



The CAPABILITY was much better than implied by grouped results.

The mean performance of all inspectors in the FAA study



Performance Data Findings

- Focus was on "human factors" in original "Have Cracks" program – primarily training
- FAA data (early 1990's) significantly better than original "Have Cracks" program
  - improvement from needle gauge to impedance plane instruments
- Current results for AF similar to FAA
  - virtually the same equipment

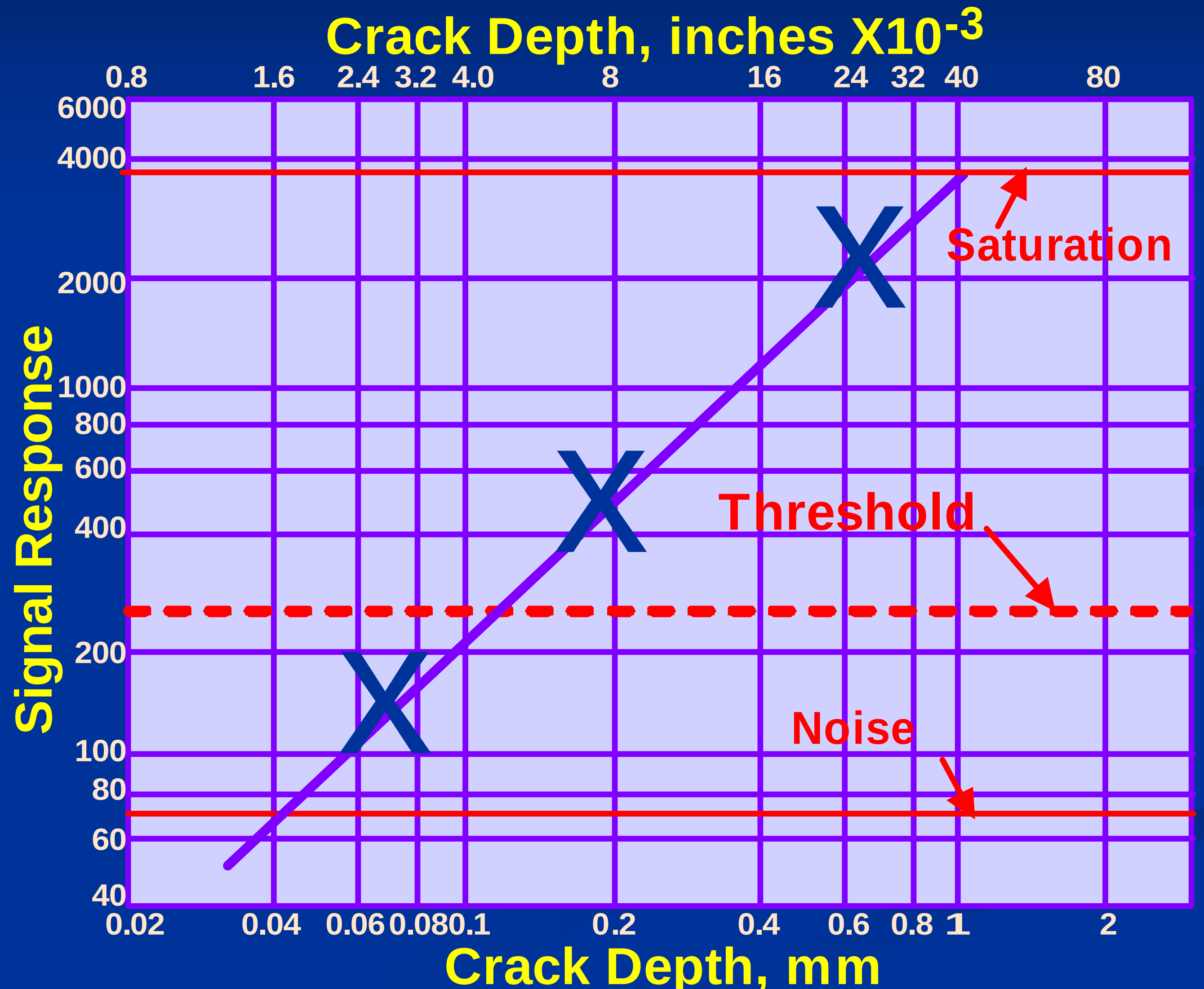
What affects inspection reliability?

- Reliability is a function of:
  - CAPABILITY – Limits of inspection system
  - REPEATABILITY
    - can I make the same inspection twice
    - calibration
  - REPRODUCIBILITY
    - can all AF depot/field sites implement the inspection and get the same results
    - process control

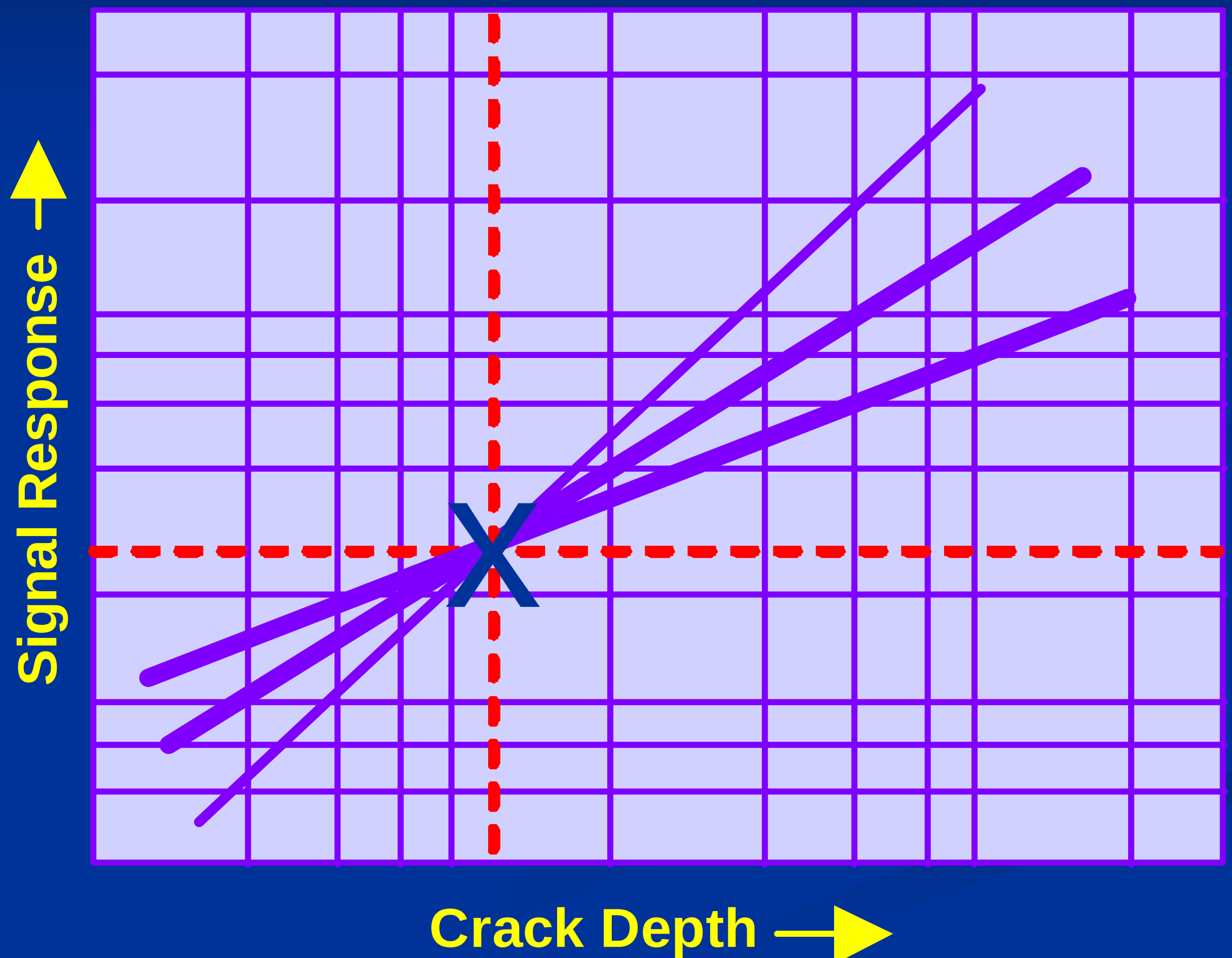
Analysis of Inspection Process Variability

- Evaluated variability in POD from inspection system variability
  - calibration
- Evaluated variability in POD from “thresholds”
  - understand detection threshold vs. POD threshold
- “Calibration”, master gauging
  - proper use of measurement science techniques
- Measurement metrics effect on POD

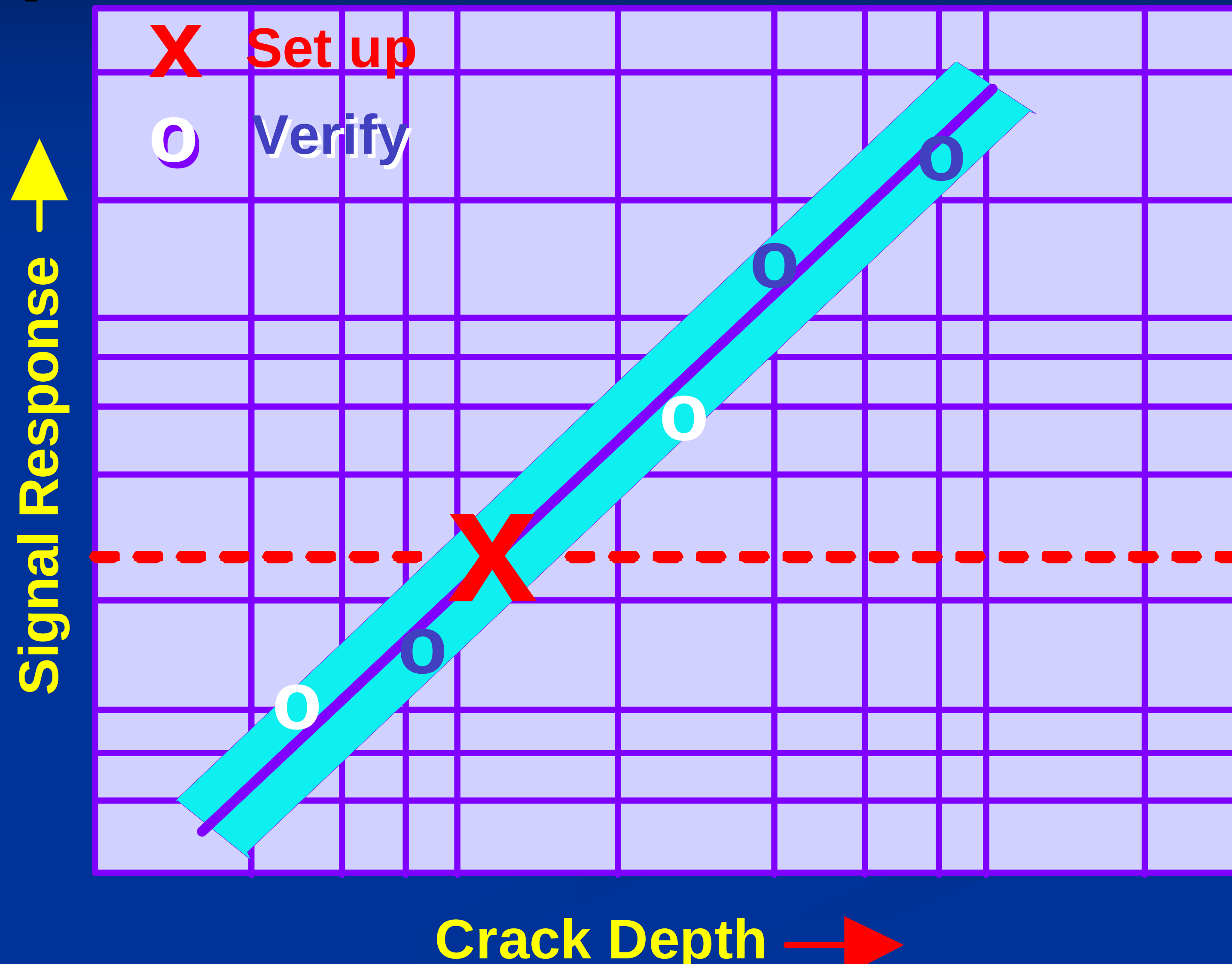
Ideal response to crack size (assumed in MIL-HDBK-1823)



Same "Calibration" Different POD's



Three Point Calibration (* see NIST recommendations)



Human factors?

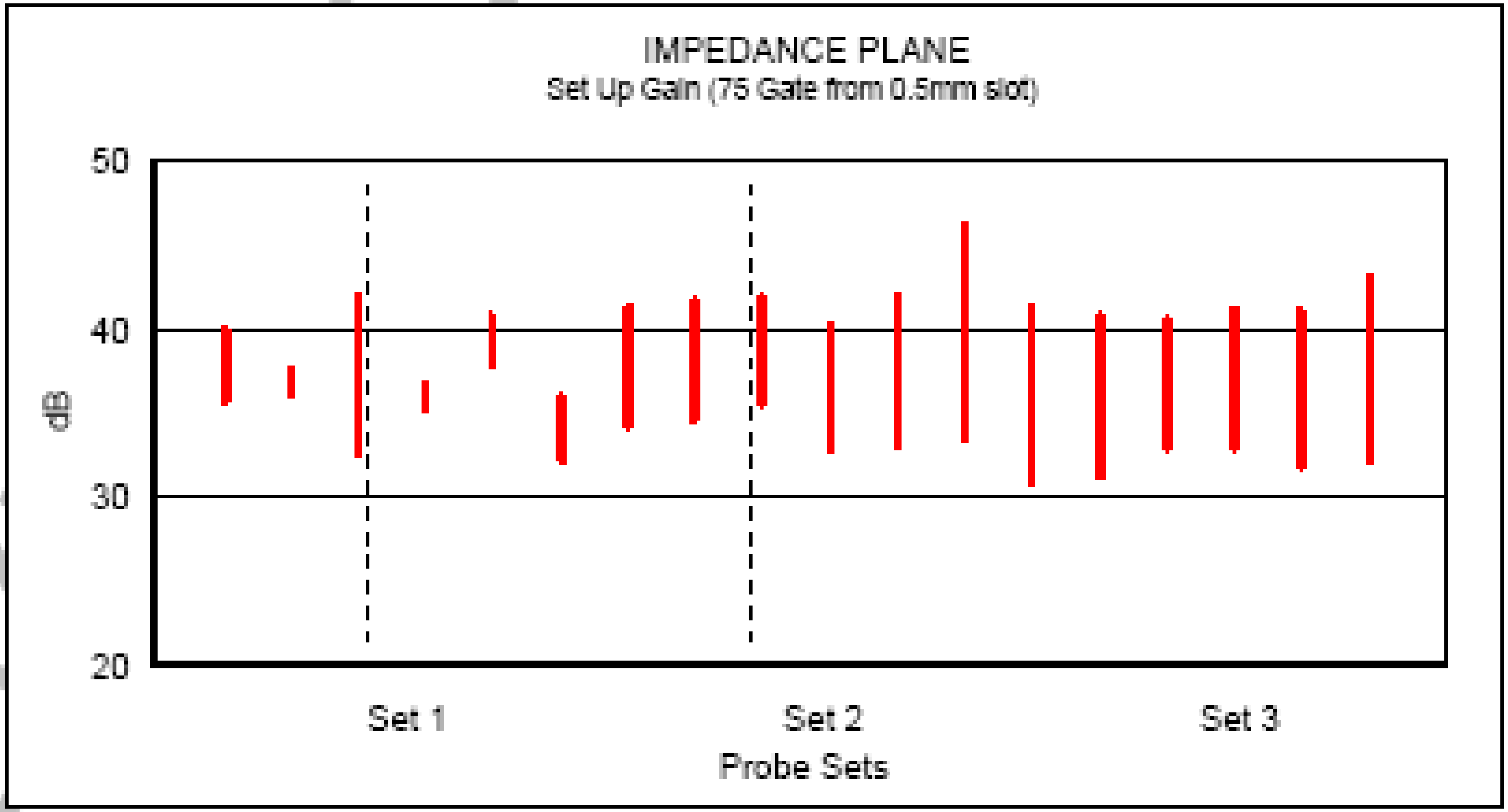
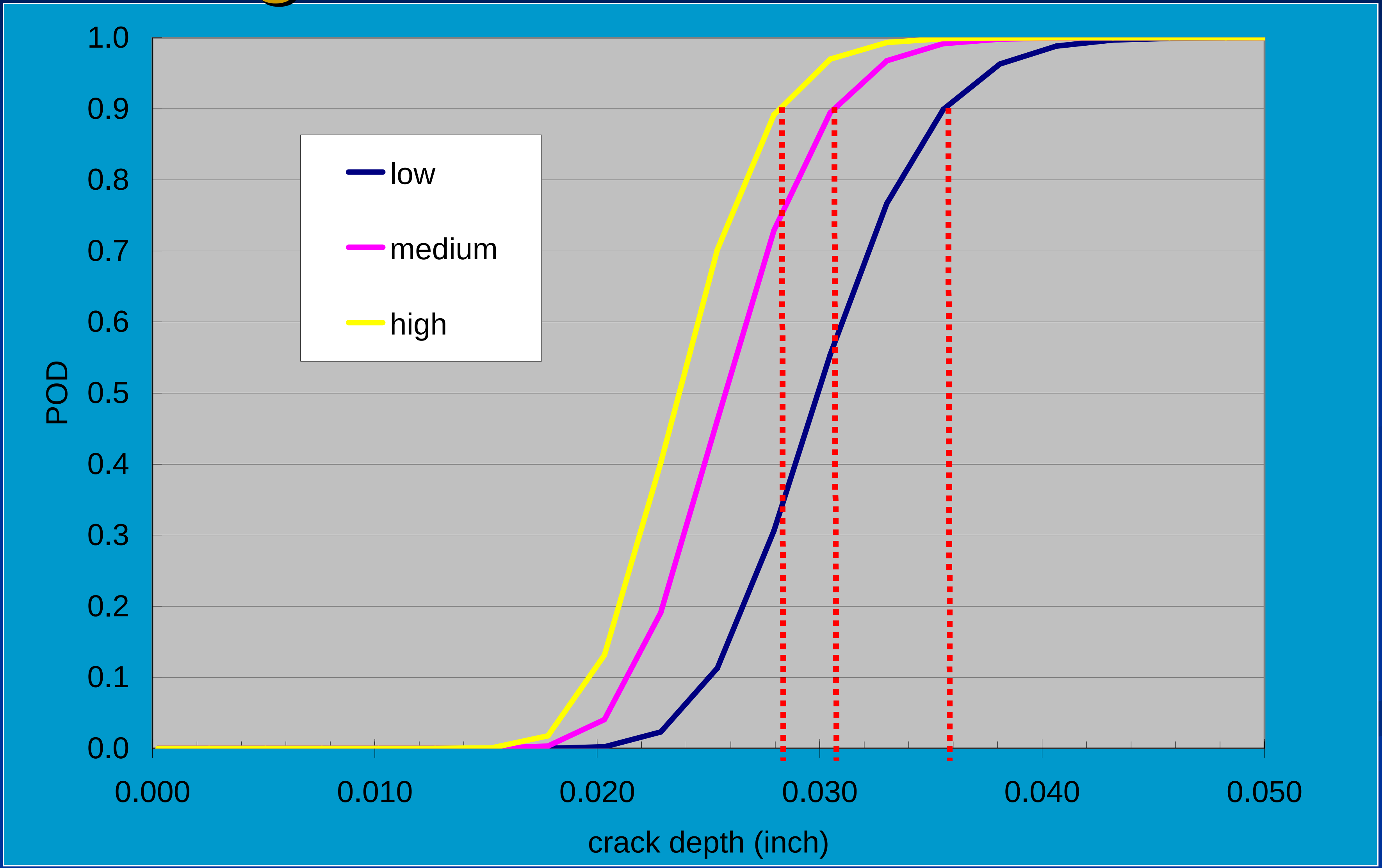


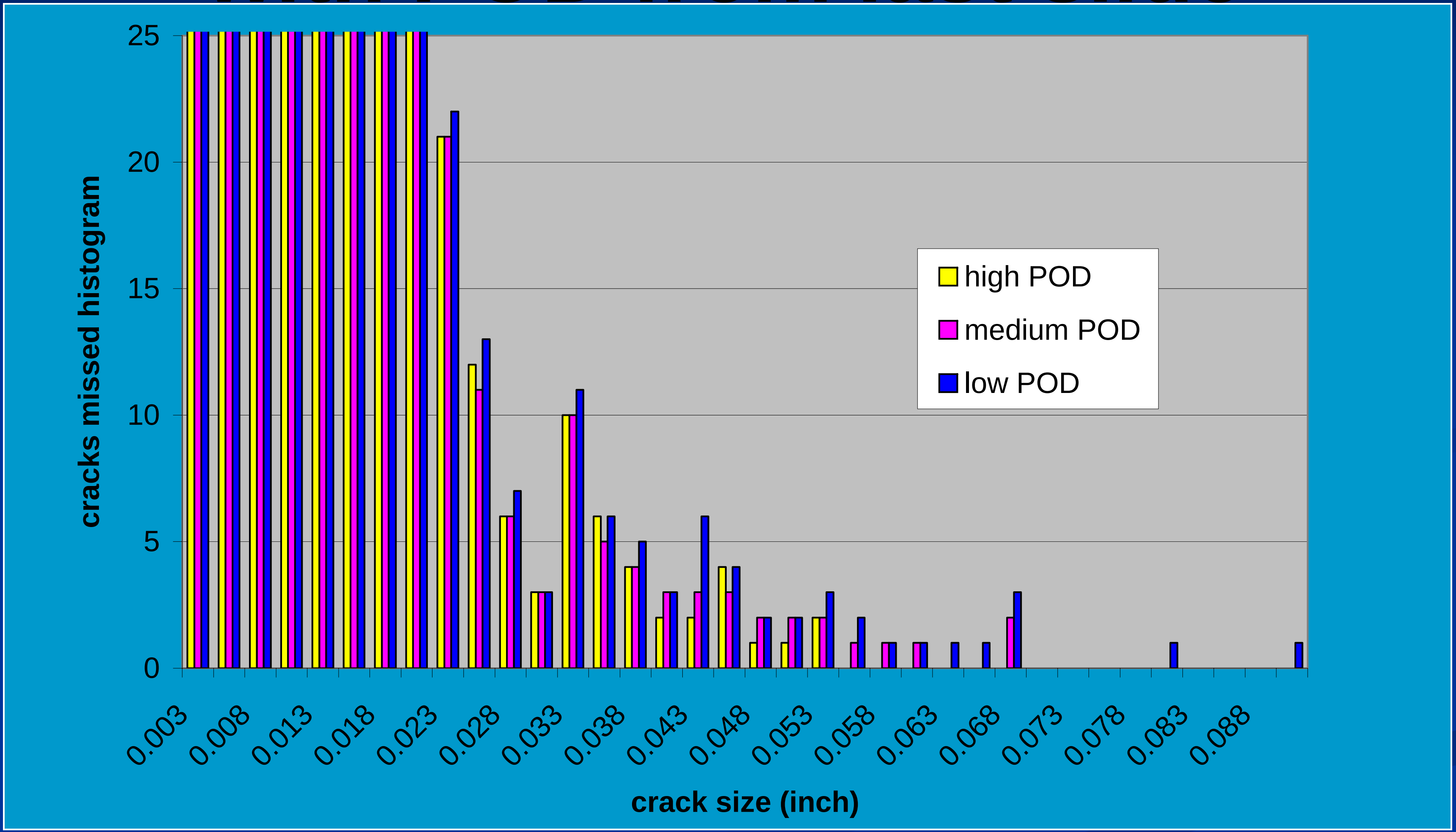
Figure C-13: A Plot of the Variation in Gain Required to Achieve the Same Signal from a 0.5 mm Slot, using Different Probes.

from NATO RTO-AVT-051 final report (available from DTIC)

Range in POD from last slide



Cracks missed by inspections with POD from last slide



A simulation of the cracks missed by the inspections of EXAMPLE C-13 applied to the estimated crack population of the A10 control point 7 at 6000 hours, 1832 inspection opportunities

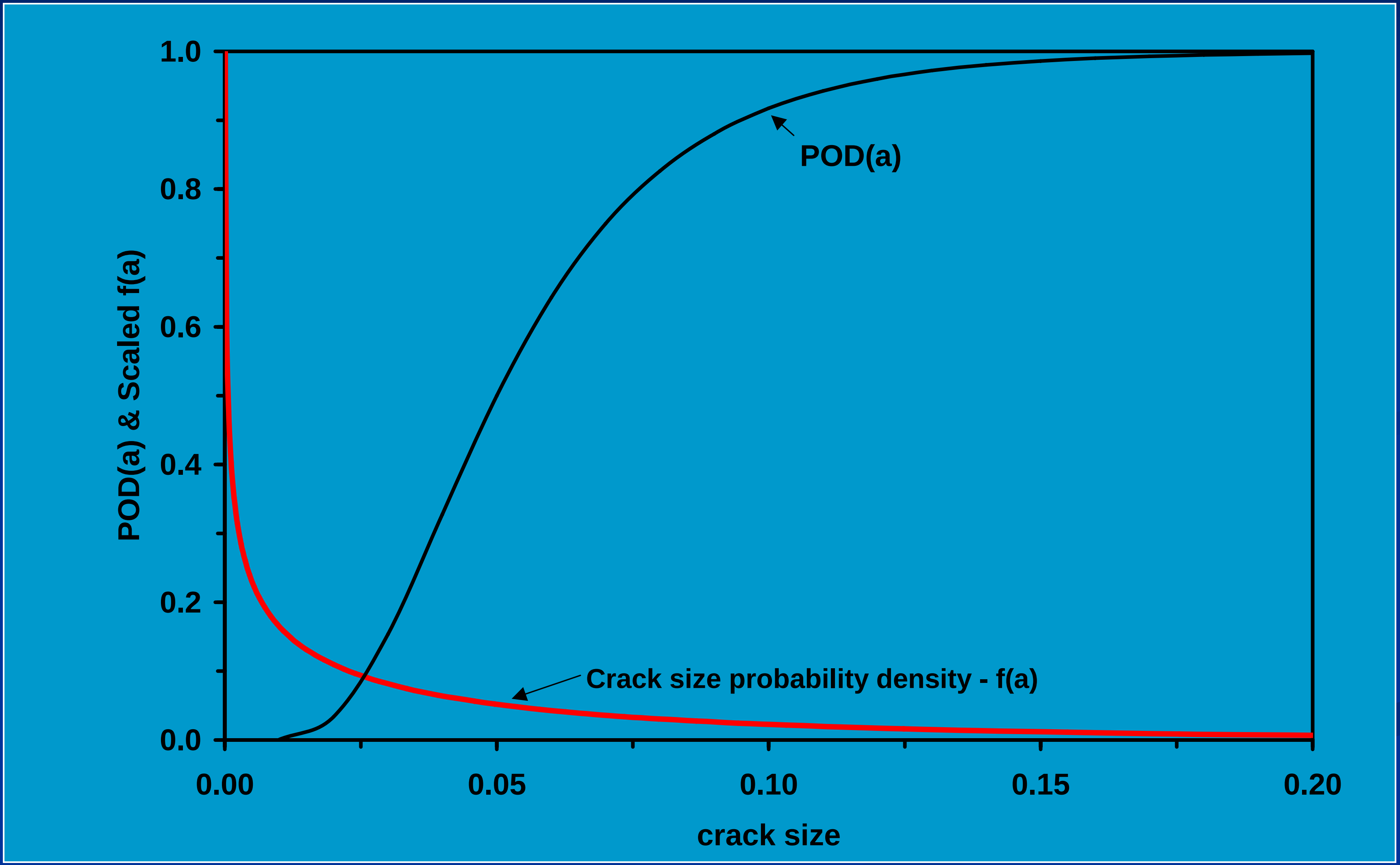
Decision Threshold

- The crack size at the decision threshold is NOT $a_{90/95}$!
  - Signals from populations of cracks of the same size are normally distributed
    - For example, if a 0.100” notch is used to set your threshold, you would expect to detect 50% of all the 0.100” notches in your population.
- The decision threshold affects both POD and “false calls” (signal and noise levels).

…next

- Analysis of in-service findings:
  - what do they say about POD, about misses
  - what do they say about risk

What is found at inspection?



What is found at inspection?

Proportion < a detected **=** $P_D(a) = \int_0^a f(x) POD(x)\,dx$

Distribution of detections **=.** $D(a) = P_D(a) / P_D(\infty)$

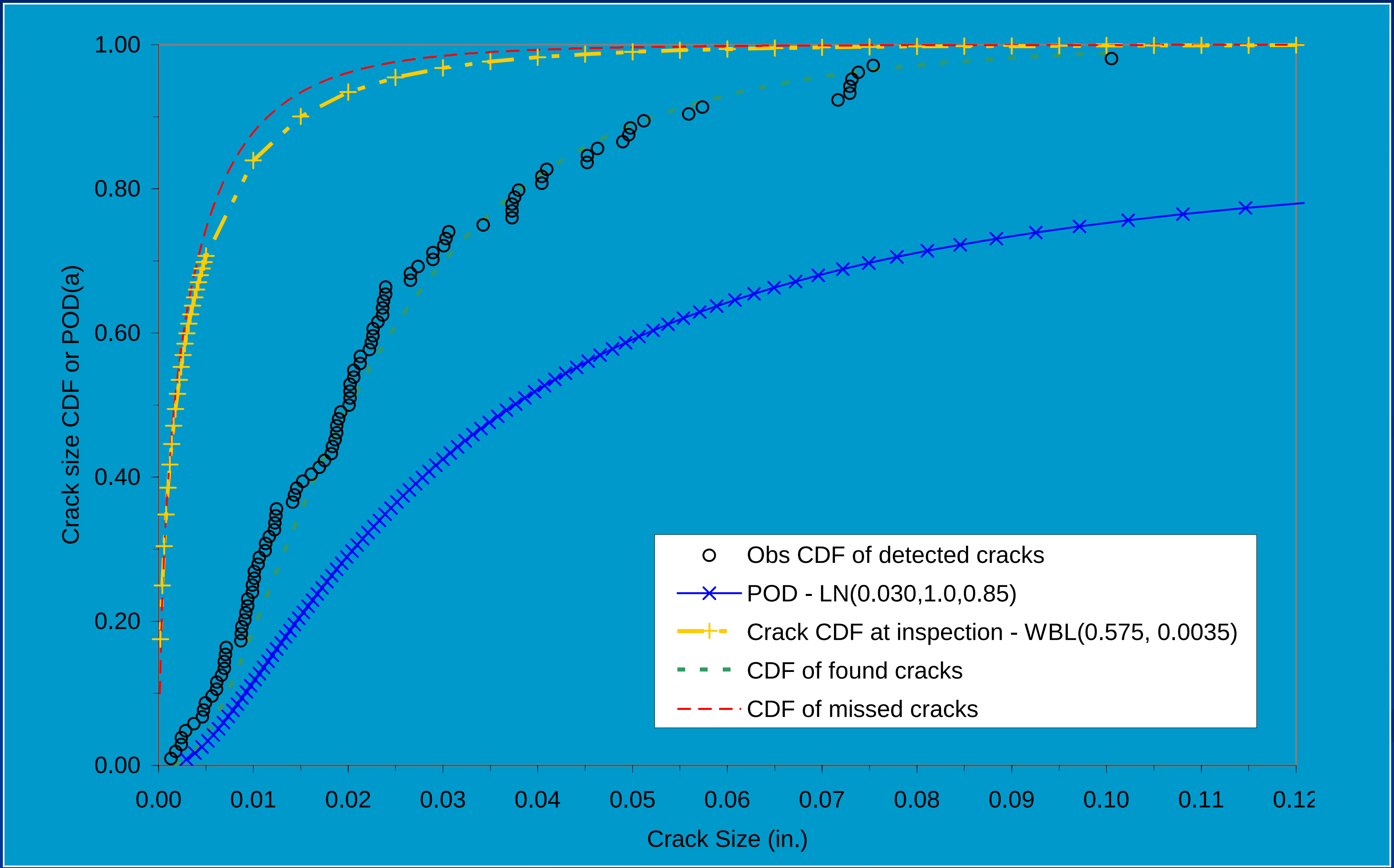
Proportion < a missed **=** $P_M(a) = \int_0^a f(x)[1 - POD(x)]\,dx$

Distribution of misses **=** $M(a) = P_M(a) / P_M(\infty)$

Crack findings

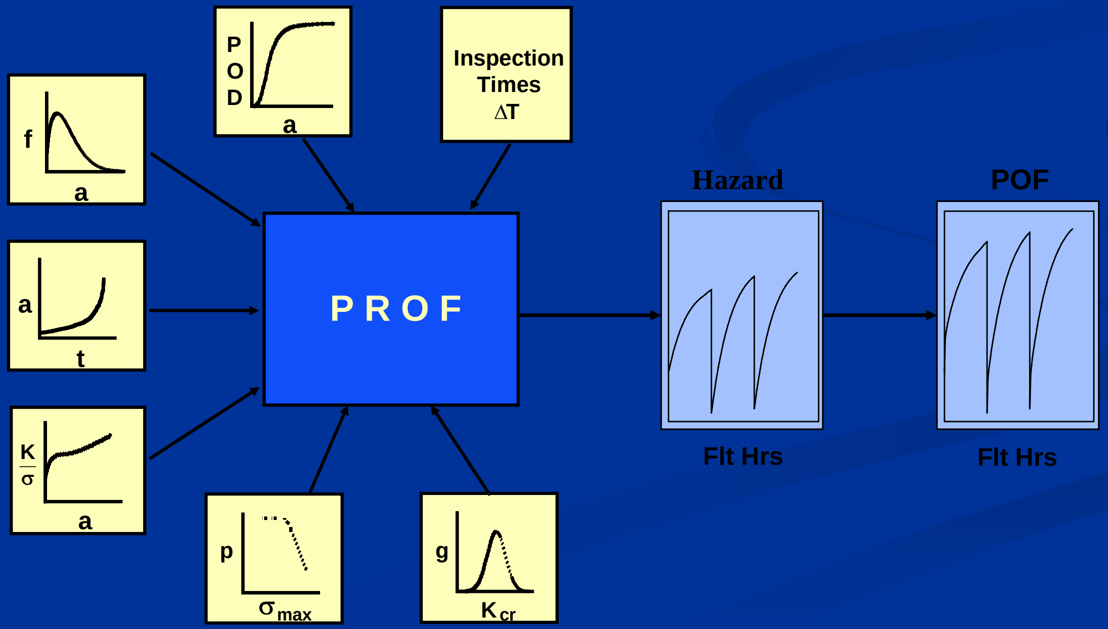
- Inspection finds are the integration of the actual crack population and the POD
- Using the crack finds population to estimate the actual population yields a biased result
  - there are many small cracks you have not found
  - YOU ONLY FOUND MOST OF THE BIG ONES
  - this biased result was used in multiple presentations at ASIP 2005, ICAF 2005 as an estimate of actual crack population

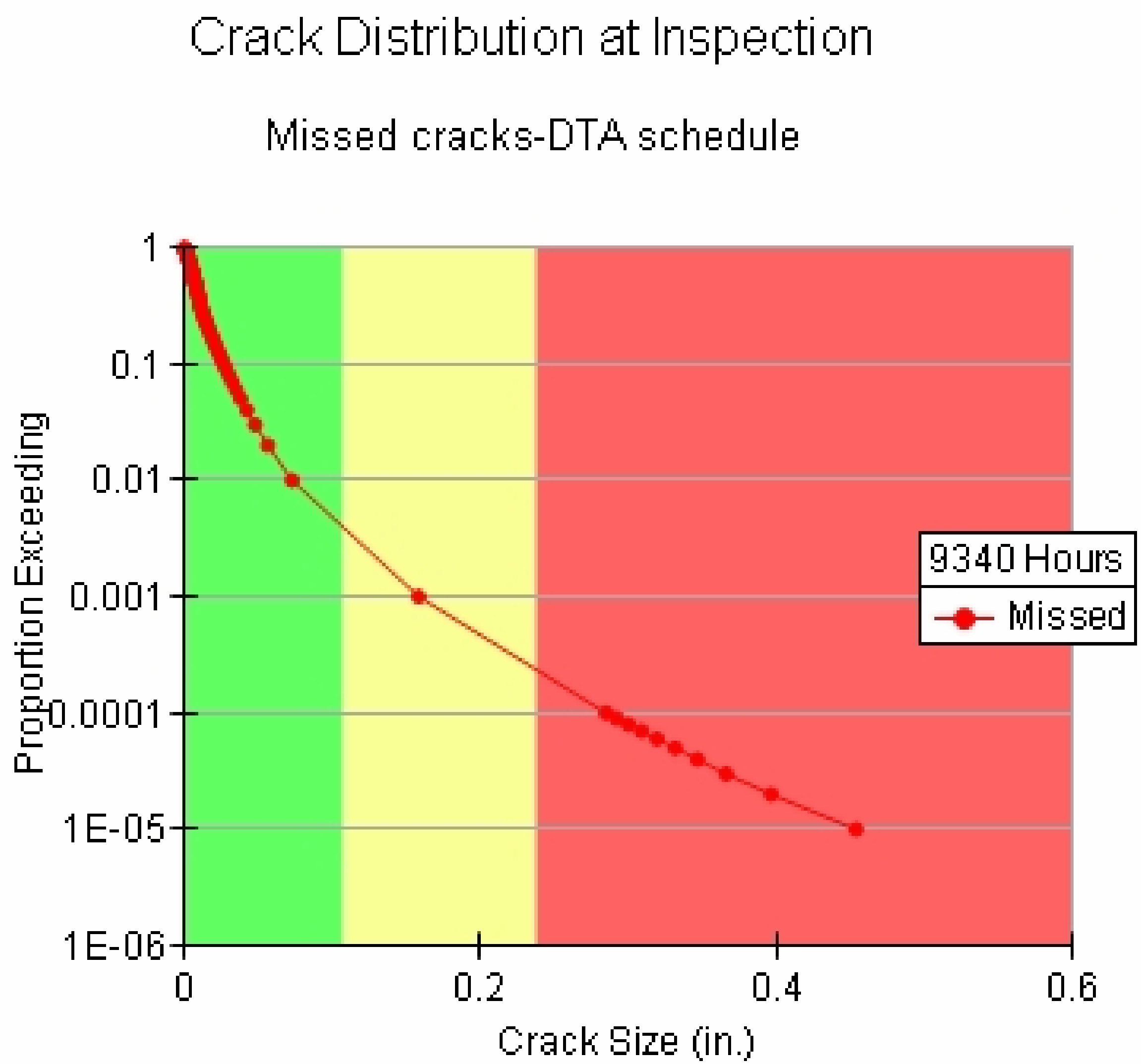
Distribution of cracks at inspection



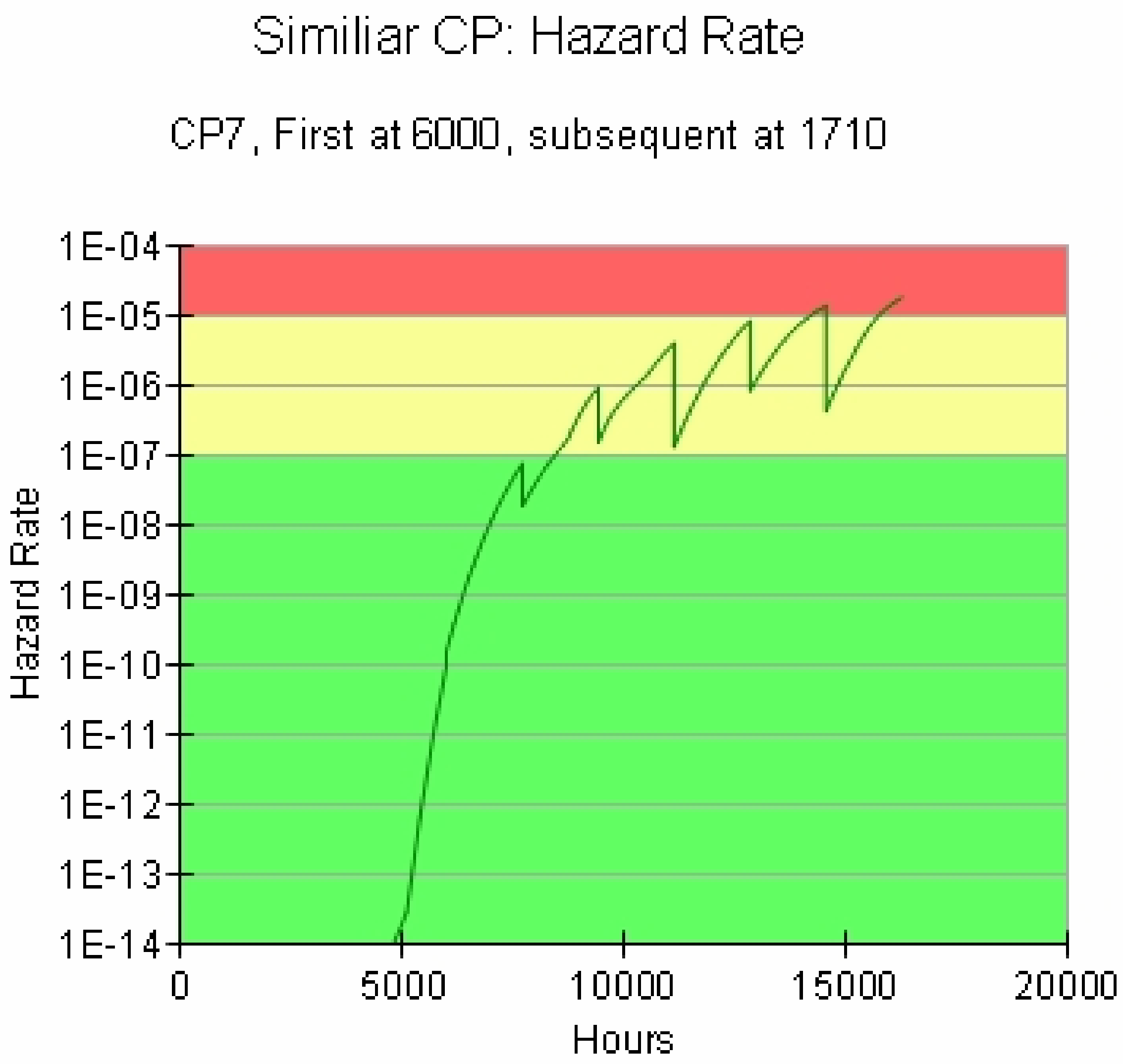
Risk Analysis - PROF

- Mil-Std-882D requirements
  - Hazard rates and/or failure probability
- Expected number of missed cracks
- Expected number of fatigue failures



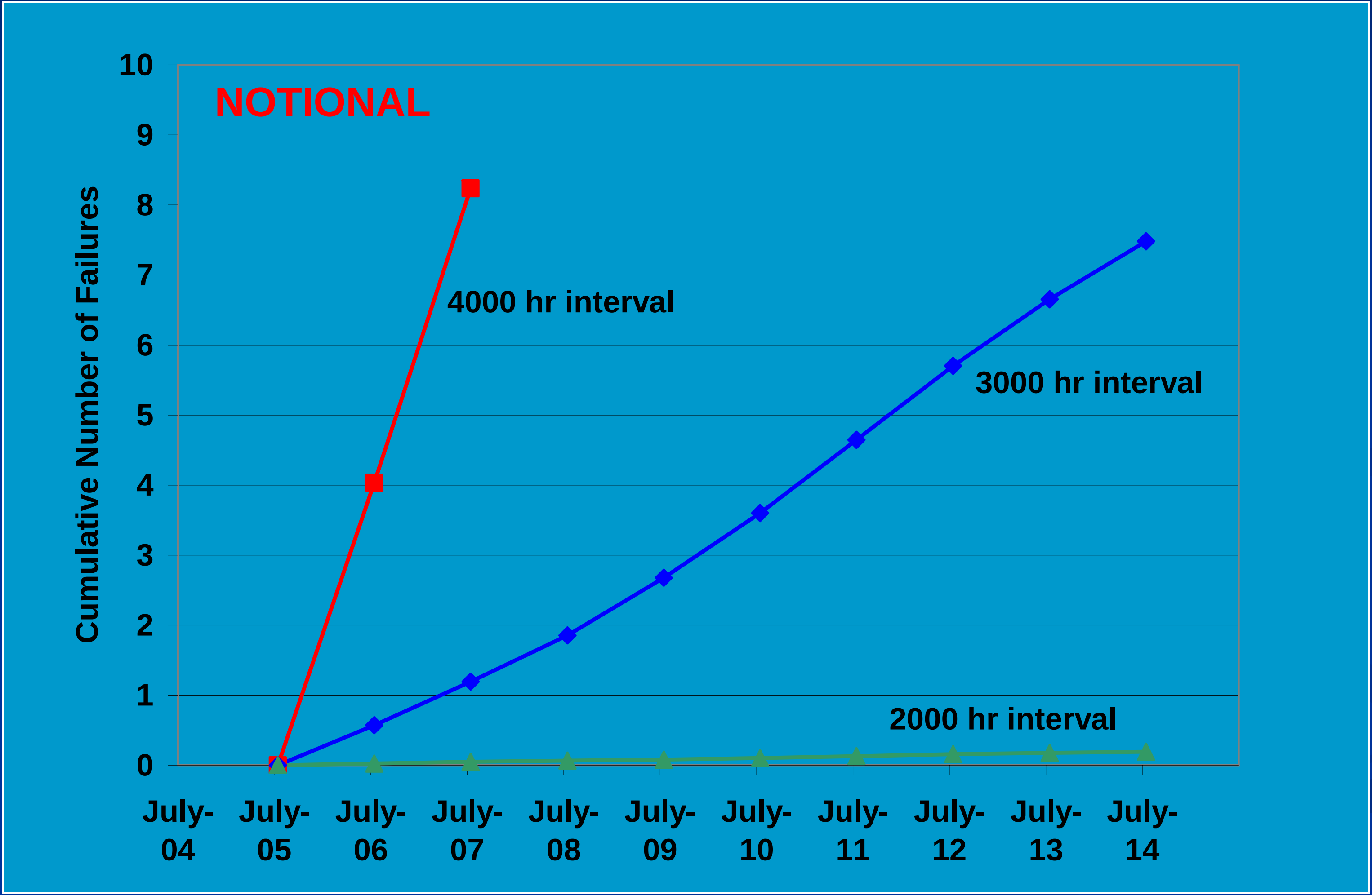


Missed crack distribution – CP 7, DTA inspections, T = 7450 hr.



PROF hazard rate for CP 7 locations – DTA inspection times.

Expected number of fleet failures



Recommended Short Term Actions:

- Do no more POD's until "calibration" and equipment issues have been resolved.
- Institute a multiple point "calibration" and master gauge program.
- Validate all fracture critical NDI procedures.
- Initiate a data base of all fleet findings for critical inspections (key input to PROF and audits).
- Develop and demonstrate methods for implementing risk analysis in fleet management

Recommended Long Term Actions:

- (Re)validate fracture critical inspections and periodically audit
  - by reference to master gauge responses
  - by duplicate inspections and review of recorded data
  - by periodic teardown of removed hardware components.
- Record information from found cracks for use in fleet management and risk assessment.
- Review and validate requirements and inspection thresholds. This may result in changing inspection intervals.

BACKUPS

Recommendations

- 1. Missing cracks greater than $a_{90/95}$ is not necessarily the fault of the inspector.
  - There are legitimate reasons for failure to detect a crack of a given size based on first principles physics of detection and measurement.
  - This has been acknowledged in the use of multiple inspection opportunities by ASIP.

Recommendations

- 2. Human factors issues ARE important in inspection performance. BUT
  - It is also necessary to focus on the measurement system in the form of
    - improved “calibration” procedures;
    - traceability of calibration artifacts;
    - validation of procedures, inspection instruments and systems (probes, cables, software and scanners).
  - Improvements in performance resulting from a focus on the physics of the system can be quantified.

Recommendations

- 3. Usefulness of large scale, “round robin” POD studies without the appropriate process control in place is doubtful.
  - Ensure measurement system has been properly defined and calibrated, and that the POD trial protocols enforce this.

Recommendations

- 4. The minimum level of inspection performance assessment for any NDI technique should consist of
  - validated procedures and validated inspection system
    - calibration of system including probes, cables, instrument
    - traceable artifacts at each inspection facility and
    - limits in the allowable variation in calibration response
- THEN targeted POD studies can be used to assess a variety of equipment, procedure, and human factors effects to determine the most cost-effective use of AF resources for improving performance

Recommendations

- 5. Within the Air Force, there is no real distinction between standard NDI procedures and fracture critical NDI procedures.
  - Fracture critical inspection procedures and associated Technical Orders (TO) should be validated.
  - Quality and currency of TO’s is known to vary widely.

Recommendations

- 6. There is significant evidence to suggest that in many cases, correct inspection of all sites is not achieved.

- This is an important element of added risk.

Recommendations

- 6. (cont.)
- In the short term, this could be addressed by:
  - a. emphasizing the importance of inspections to fleet managers and inspectors.
  - b. allocating sufficient resources to complete inspections without impacting operational requirements.
  - c. instituting tighter management controls with more complete record keeping.
  - d. involving inspectors in the feedback of inspection results to the structural analyses/ risk assessment of the system engineering process.

Recommendations

- 7. The use of the $a_{90/95}$ value as a threshold in inspection capability has obscured the fact the inspections are a stochastic process.

- POD assumptions should be validated.
  - Priority to safety-critical cases.

- Unknown POD = unknown risk. This risk increases as fleets age and the crack population grows in size.

Recommendations

- 8. At present, the DTA inspection interval is determined from only the a90/95 crack size that characterizes inspection capability.

- It does not account for the chances of the inspection not being performed in accordance with the TO’s.
  - A method should be developed for accounting for the probability of this occurence.

Recommendations

- 9. Non-deterministic criteria should be considered for establishing inspection intervals.
- PROF is an available Air Force risk analysis tool that predicts
  - a) the distribution of crack sizes missed at an inspection;
  - b) the hazard rates of Mil-Std-882D; and,
  - c) the expected numbers of future failures resulting from the timing of inspections.
- These types of information could provide the basis for developing and evaluating inspection intervals.

Recommendations

- 10. There is critically important information in the sizes of the cracks detected at inspections.
- The measurement and recording of actual detected crack sizes should be initiated and may be as simple as use of replication techniques.
- This is a key component of any long-term NDI performance audit program.

Recommendations

- 11. In the medium to long term, inspection equipment and databases should be required to record all inspection results, not only indications. This will allow thorough audits to ensure that inspections have been performed as required in TO's.