

Progress in Model Assisted Probability of Detection (MAPOD)

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- Why?
- What?
- What has happened so far?
- The Many Paths to MAPOD
- Examples
- Conclusions

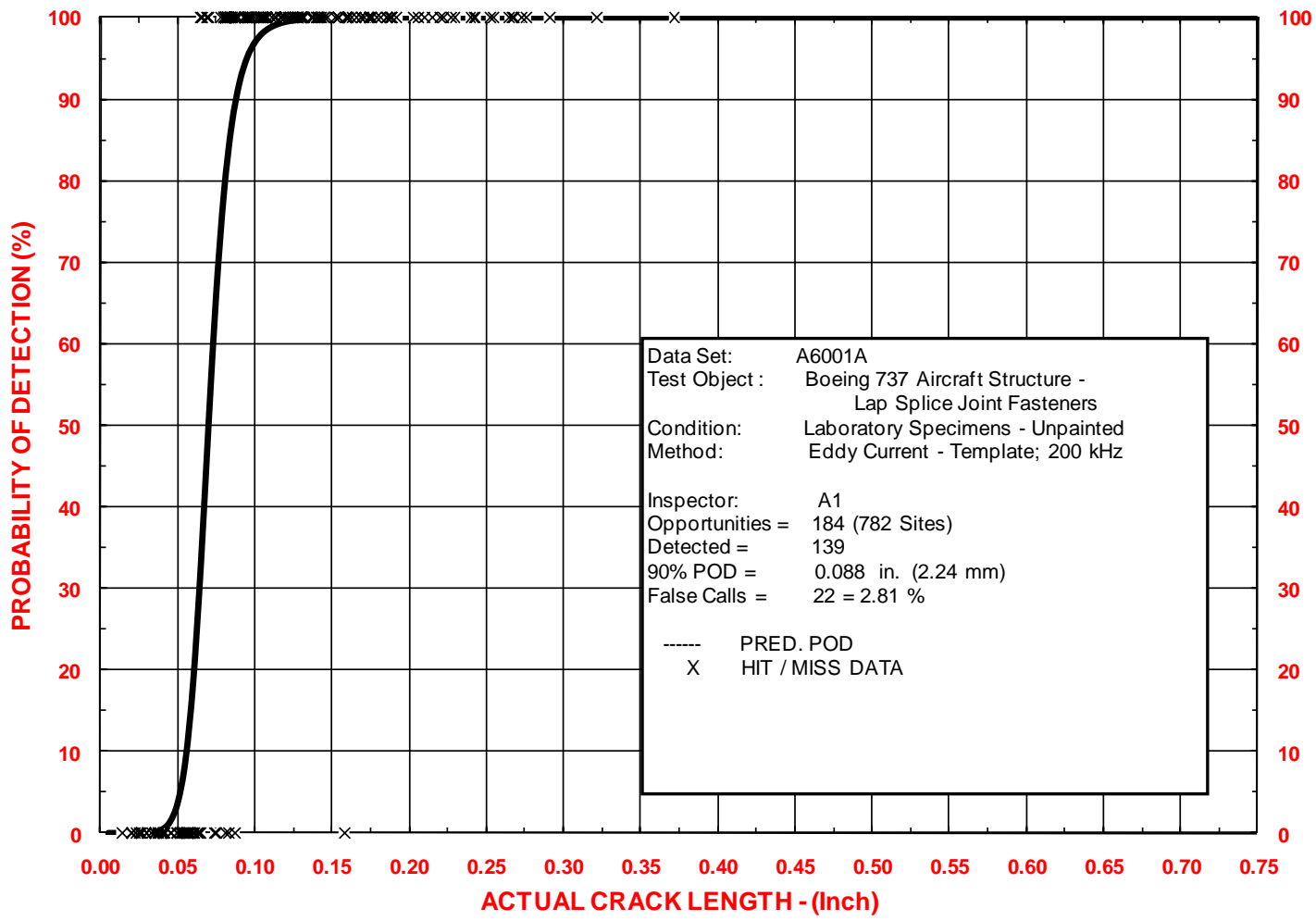
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Why?

- Performance measurement of nondestructive testing/inspection/evaluation (NDT) commonly uses Probability of Detection (POD) as the metric.
- Required (or at least accepted) for inspection scheduling, risk assessment under many regulatory regimes.
 - USAF, FAA, NASA, NRC, ASME, API, ...

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What is POD?



From NDE Capabilities Databook, <http://ammtiac.alionscience.com>

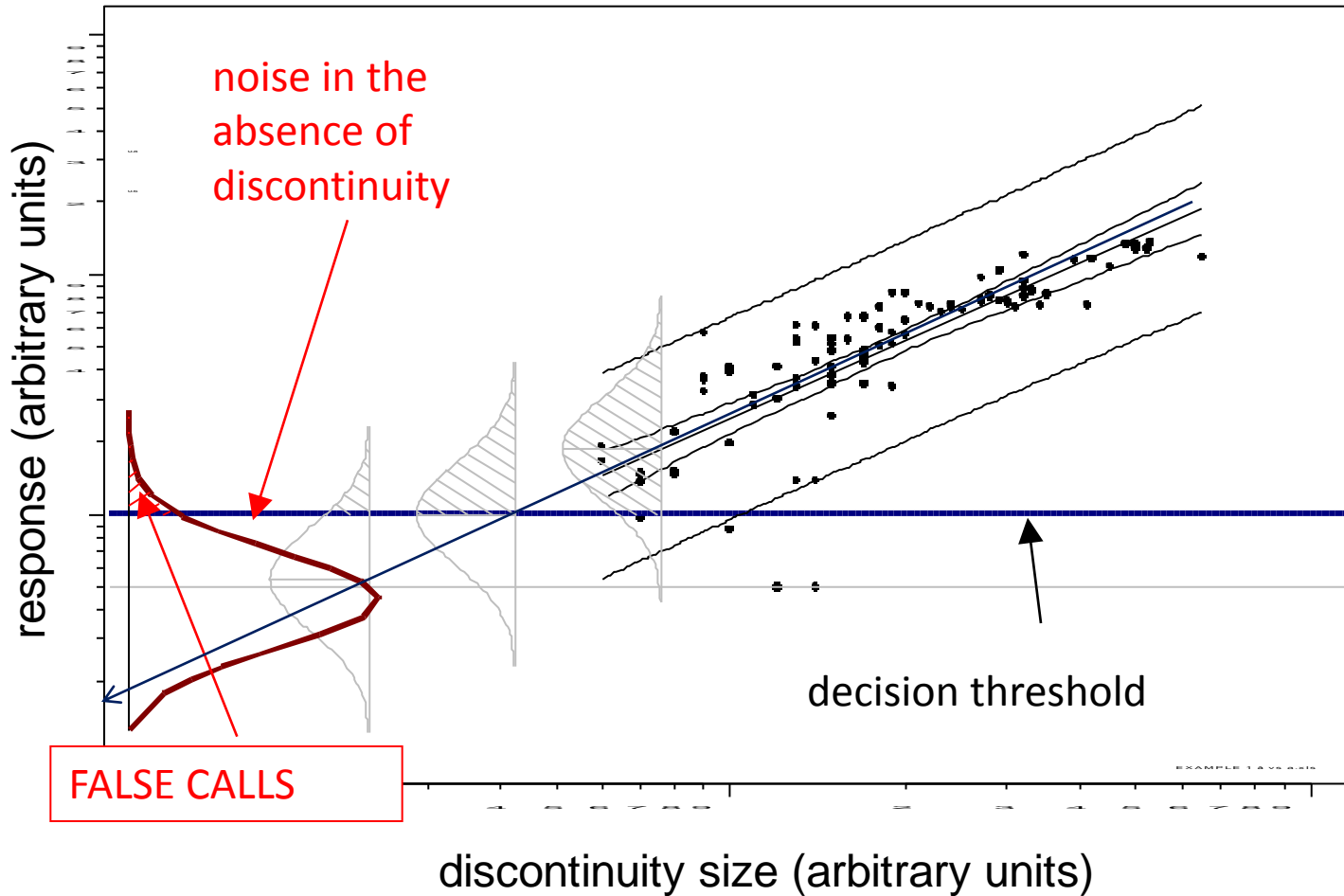
How to get POD?

- Empirical experiments as described in MIL-HDBK-1823.
 - 40 – 60 cracked samples
 - 3x as many uncracked samples
 - Population of inspectors
- = time and money!
- “Engineering Justification” allowable in some industries/jurisdictions.
 - But we would like to enforce some rigor!

- Obvious question #1:
- If I can predict the response of NDT system, why can't I use the same model to predict the reliability?
 - Included as viable option in latest edition of MIL-HDBK-1823.
 - Full Model Assisted (FMA) approach to MAPOD

MIL-HDBK-1823 model

$$\hat{\ln a} = \beta_0 + \beta_1 \ln a + \varepsilon$$



How to get POD? MAPOD!

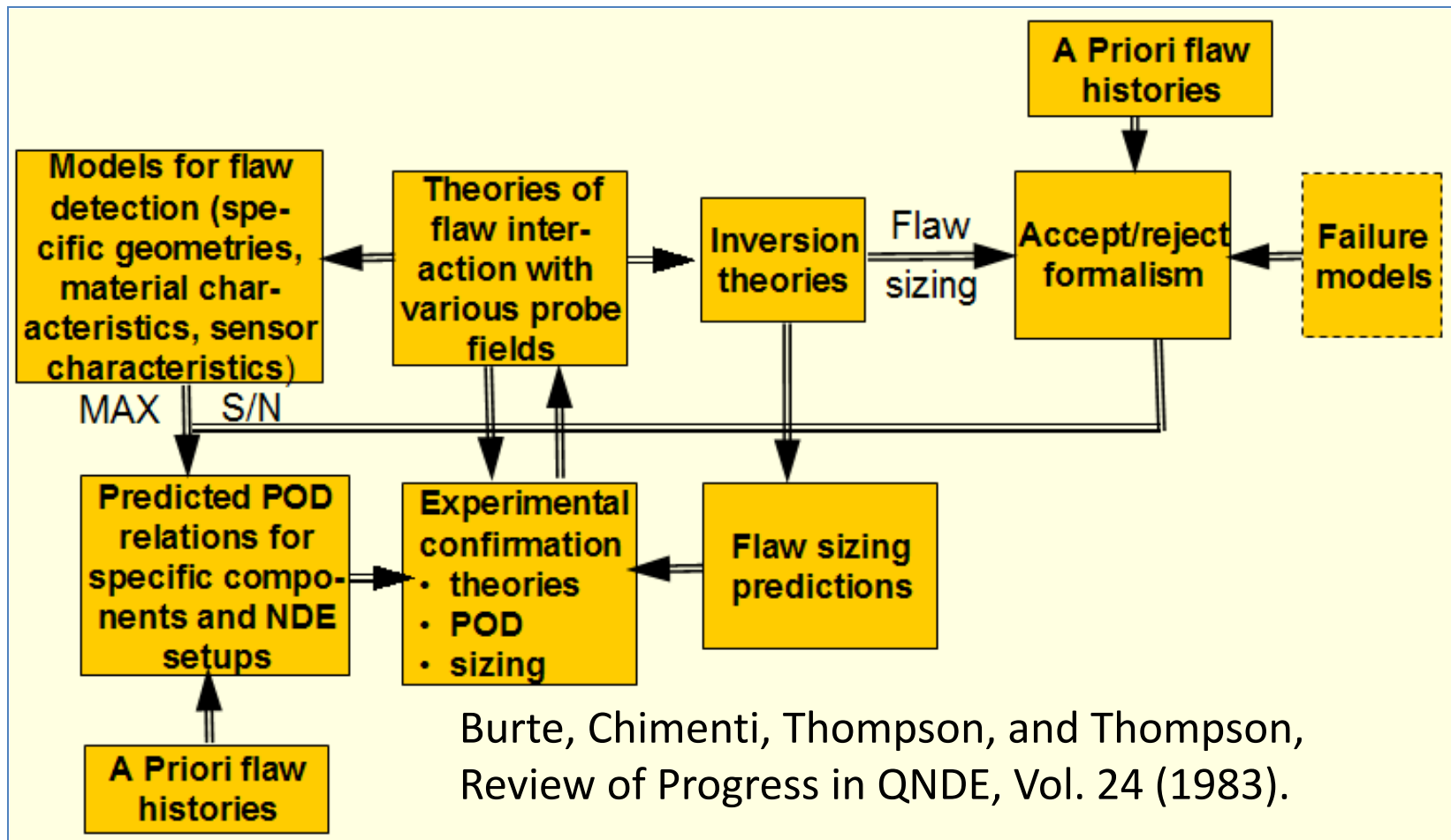
- Obvious question #2:
- Why not make one complex specimen. Make a whole bunch of simple specimens. Find relationship between the two
 - i.e. (signal from complex) = 0.5 x (signal from simple)
 - Now use simple specimens to get all the data.
 - Included as viable option in latest edition of MIL-HDBK-1823.
 - Transfer Function (XFN) approach to MAPOD.

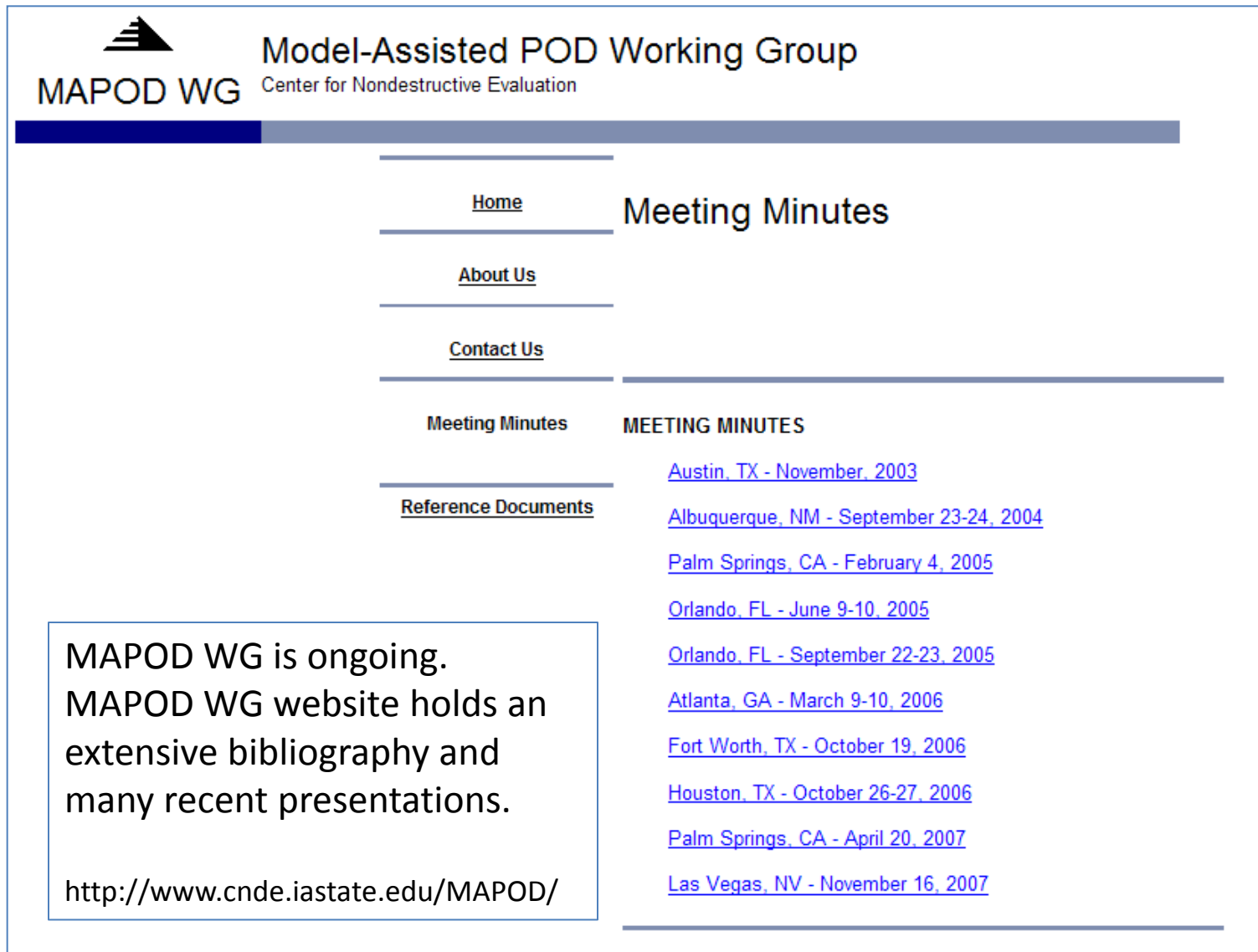
- Why?
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- **What has happened so far?**
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- A fait accompli?
- Conclusions

- * well, maybe not EVERYTHING.
- Department of Defense operates
- Defense Technical Information Center (DTIC) operates
- Information Analysis Centers (IACs) including
- Advanced Materials, Manufacturing, and Testing IAC (AMMTIAC)
- DTIC over 2 M holdings in library.
 - <http://www.dtic.mil>
- AMMTIAC over 300K holdings in library
 - <http://ammtiac.alionscience.com>
- AMMTIAC provides free inquiry service TO YOU!

What has happened so far?

- Ideas have been around for some time.





The screenshot shows the MAPOD WG website. At the top left is the TRI logo and the text 'MAPOD WG'. To the right is the title 'Model-Assisted POD Working Group' and the subtitle 'Center for Nondestructive Evaluation'. A navigation menu on the left includes links for 'Home', 'About Us', 'Contact Us', 'Meeting Minutes', and 'Reference Documents'. The 'Meeting Minutes' section is active, displaying a list of meeting dates and locations: Austin, TX - November, 2003; Albuquerque, NM - September 23-24, 2004; Palm Springs, CA - February 4, 2005; Orlando, FL - June 9-10, 2005; Orlando, FL - September 22-23, 2005; Atlanta, GA - March 9-10, 2006; Fort Worth, TX - October 19, 2006; Houston, TX - October 26-27, 2006; Palm Springs, CA - April 20, 2007; and Las Vegas, NV - November 16, 2007. A text box on the left states that the MAPOD WG is ongoing and provides a URL to the website.

MAPOD WG Model-Assisted POD Working Group
Center for Nondestructive Evaluation

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MAPOD WG is ongoing.
MAPOD WG website holds an extensive bibliography and many recent presentations.

<http://www.cnde.iastate.edu/MAPOD/>

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- Any combination of empirical data, transfer function, model data.
- Expertise required:
 - What variables are important to capture?
 - How to capture them?
 - How to integrate into final POD estimate?
 - Confidence bound?
- NDT engineering, statisticians.

- Checklist of variables that you might want to consider for typical applications.
 - Specimen parameters.
 - Geometry, material, manufacturing, ...
 - Defect parameters
 - Crack nucleating feature, stress levels, orientation, aspect ratio...
 - Inspection parameters
 - Equipment, probe, setup,
 - Inspector parameters
 - Training, experience, environment, access...

- FOR EACH VARIABLE:
- Mean, variability, error in both
 - epistemic and aleatory
- How did you get the above?
 - Empirical, model, transfer function

- **OUTPUTS:**
 - POD and confidence bound.
- **Obvious Question #3: What is the confidence bound on a POD curve?**
 - Estimate of the error likely because you took a finite number of samples from the total population.

- Obvious Question #4 and on...
 - What is confidence bound on model data?
 - What is confidence bound on transformed empirical data?
 - What is confidence bound on combinations of the above?
- Note that the confidence bound is a regulatory requirement for certain customers.

Shhhh don't tell anyone

- IMHO, confidence bound is not what the customer wants. Or at least is only a part.
- Want to know:
 - 1. Some quality metric of the POD experiment.
 - 2. Some metric of the variability in results to be expected when the inspection is performed.

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- Empirical data.
 - Forsyth (TRI) and Butcher (DND Canada)
- Transfer functions.
 - Smith (P&W), Hugo and Harding (DSTO), Mandache (NRCC)
- Models.
 - Thompson et al.(CNDE), Nakagawa (CNDE), Meeker (CNDE), Aldrin and Knopp (AFRL), Sabbagh (VIC3D) and Aldrin.
- Mixed model and empirical.
 - Aldrin and Spencer and Forsyth, Aldrin and Sabbagh.

Example 1



ATESS

Excellimus Auxilio

Excellence In Support

Aerospace and Telecommunications Engineering Support Squadron

Canadian Forces Generic Bolt Hole Eddy
Current Probability of Detection Study

ASIP 2007

05 Dec 2007 Palm Springs, CA

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Example 1

- $\beta_0, \beta_1, \varepsilon$ derived empirically from traditional MIL-HDBK-1823 experiment
- $\varepsilon_{h.q.}$ (hole quality effect) also empirical, from a separate experiment.

signal

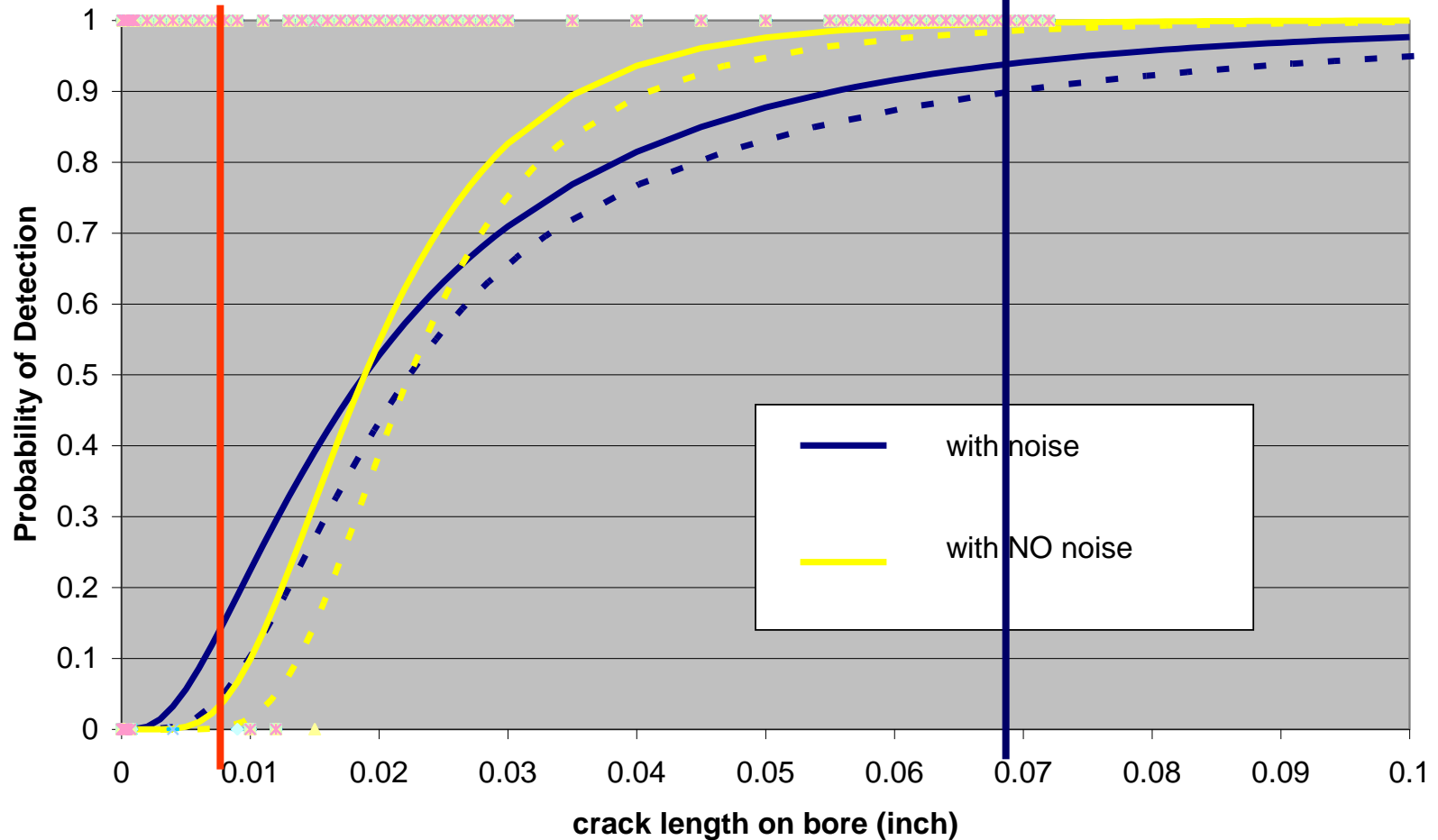
crack size

random noise

$$\ln \hat{a} = \beta_0 + \beta_1 \ln a + \varepsilon + \varepsilon_{h.q.}$$

Example 1 - POD

POD - IAR Configuration 5
with noise, threshold = 1.57 div, false call rate = 1%



- What about answers to questions 4?
- “Credibility bounds”
- Option: Propagate distributions of input variables through the models. Perform Monte Carlo runs to characterize the distribution of outputs.
- Option: Use Bayesian methods to update distributions (combine data from different sources). Not exclusive.

Example 2: Model fit and confidence bounds.

Ex: \hat{a} versus a_1 and a_2 model fit: $\hat{a} = \beta_0 + \beta_1 a_1 + \beta_2 a_2 + \varepsilon$

- **Explore: Case study 3: dep_fixed** - POD(a_1, a_2) generated for varying a_1 and for a dependent variable $a_2(a_1)$ using a deterministic model
 - POD plot over a uniform distribution of a_1
 - $a_2 = m a_1$ where: m is a constant value = 0.33

- **Compare different model fit and confidence bounds approaches**

- Analysis 0: Neglect a_2
- Analysis 1: Regression fit, Delta method for confidence bds (ahat versus a_1 and a_2)
- Analysis 2: Regression fit, Monte Carlo for confidence bds (ahat versus a_1 and a_2)
- Analysis 2: Bayesian (MCMC) for model fit and confidence bds (ahat versus a_1 and a_2)

	Analysis 0	Analysis 1	Analysis 2	Analysis 3
	survreg()	survreg()	glm()/MC	BayesMCMC
	neglect a2	use a1, a2	use a1, a2	use a1, a2
B0	-0.05780	-0.05986	-0.05986	-0.05983
B1	5.39532	2.77503	2.77503	2.77668
B2	0.00000	6.65178	6.65178	6.64630
Delta	0.02538	0.02001	0.02001	0.02061
Threshold	0.10000	0.10000	0.10000	0.10000
var11	0.00003	0.00002	0.00002	0.00002
var22	0.00912	0.11971	0.12346	0.12687
var33	0.00000	0.73494	0.75790	0.78247
a50	0.02925	0.03204	0.03204	0.03203
a90	0.03529	0.03719	0.03721	0.03732
a90/95	0.03616	0.03720	0.03837	0.03733

- ***Inclusion of a_2 reduces residual variance (Delta)***
- ***Very little difference observed between the three methods (1-3) for this case***

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- MAPOD is pretty well established.
 - Is being used already.
 - Is in MIL-HDBK-1823.
- Not all questions are answered.
 - Confidence bounds / quality metrics.
- No tools available yet for community.
 - TRI/Austin and Computational Tools are planning a public, free release of NDIToolkit™.