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Progress in Model Assisted Probability of Detection (MAPOD)

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AA&S 2011, 18 – 21 April 2011, San Diego

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Outline

- 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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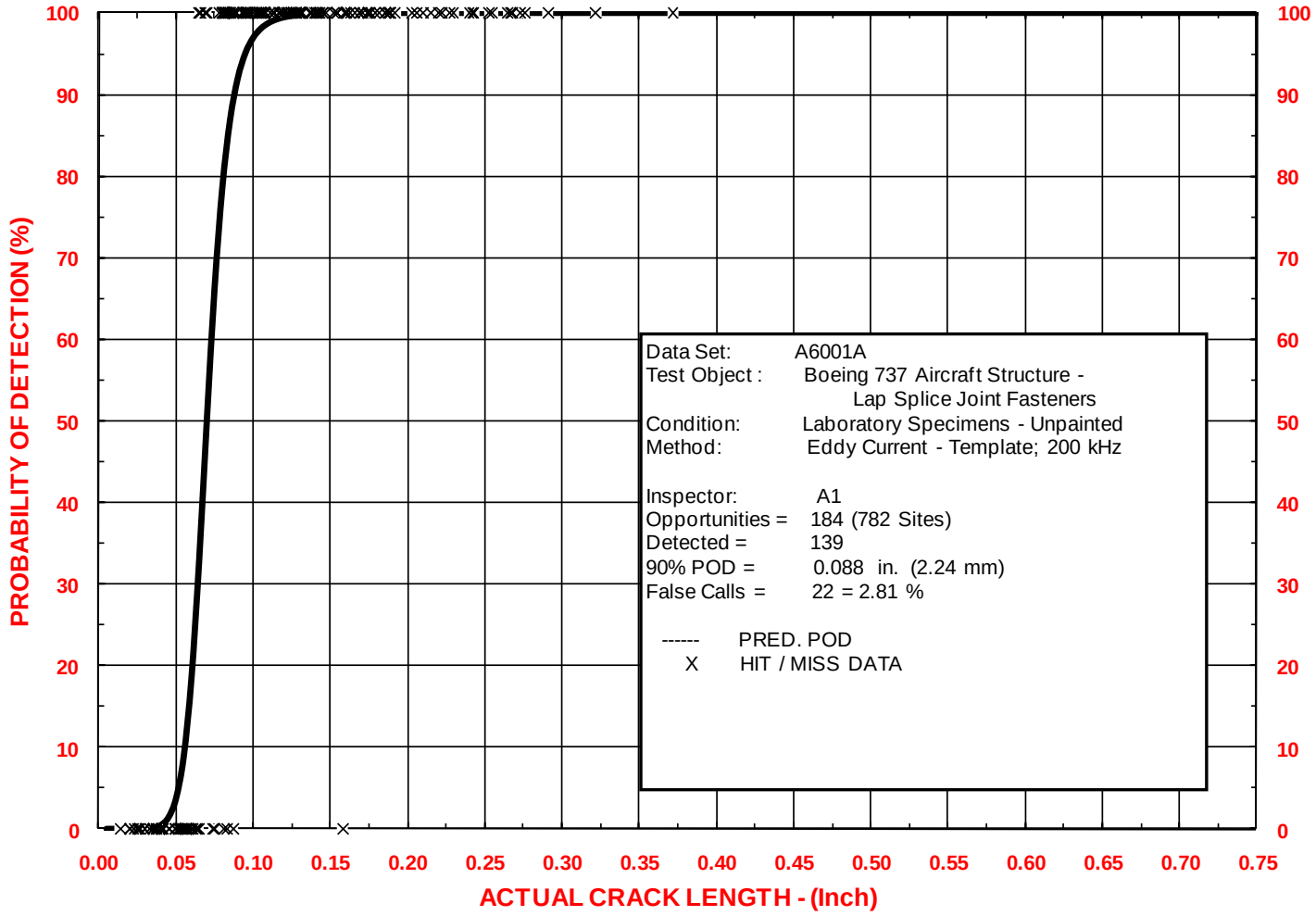
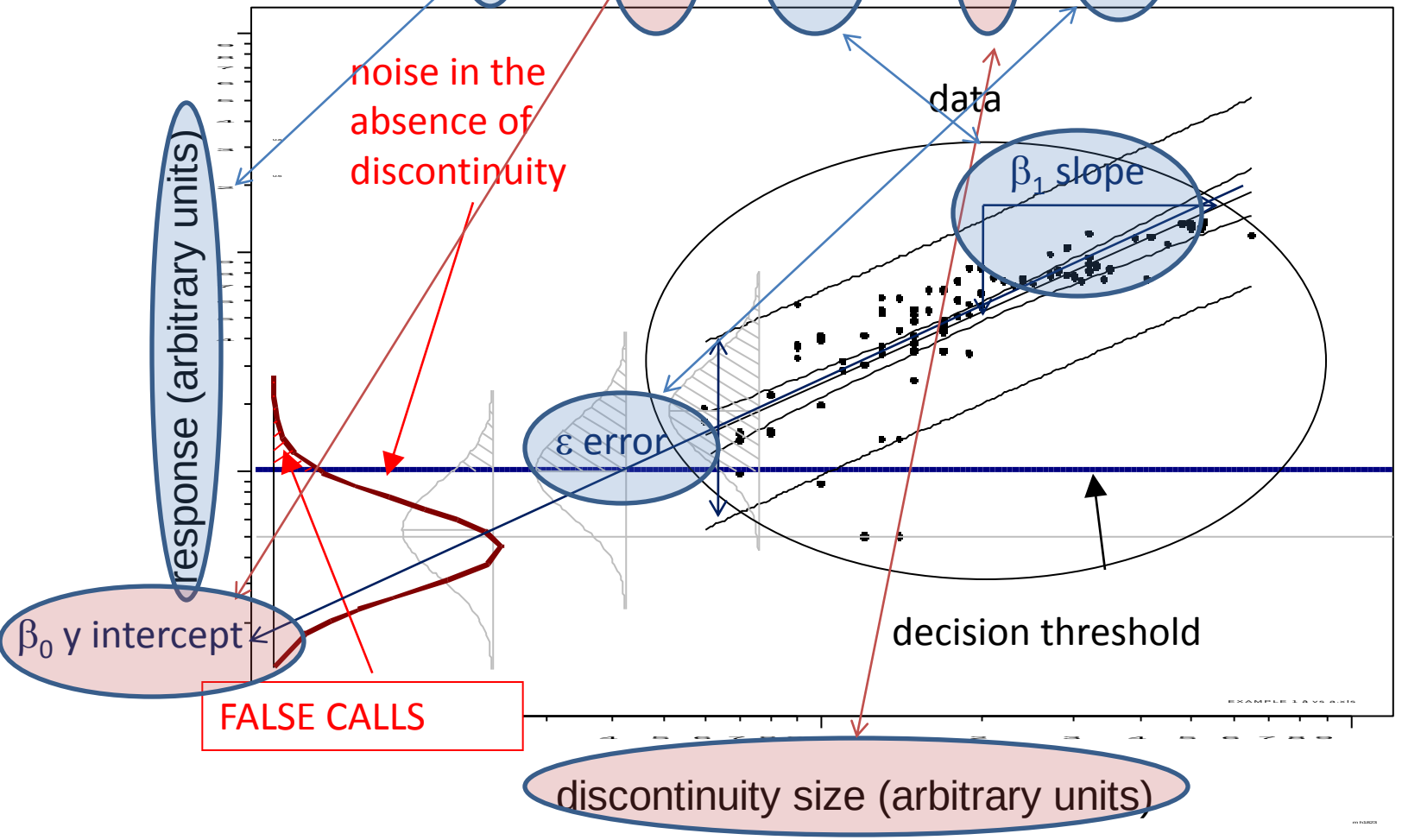
What is POD?



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

MIL-HDBK-1823 model

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



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!

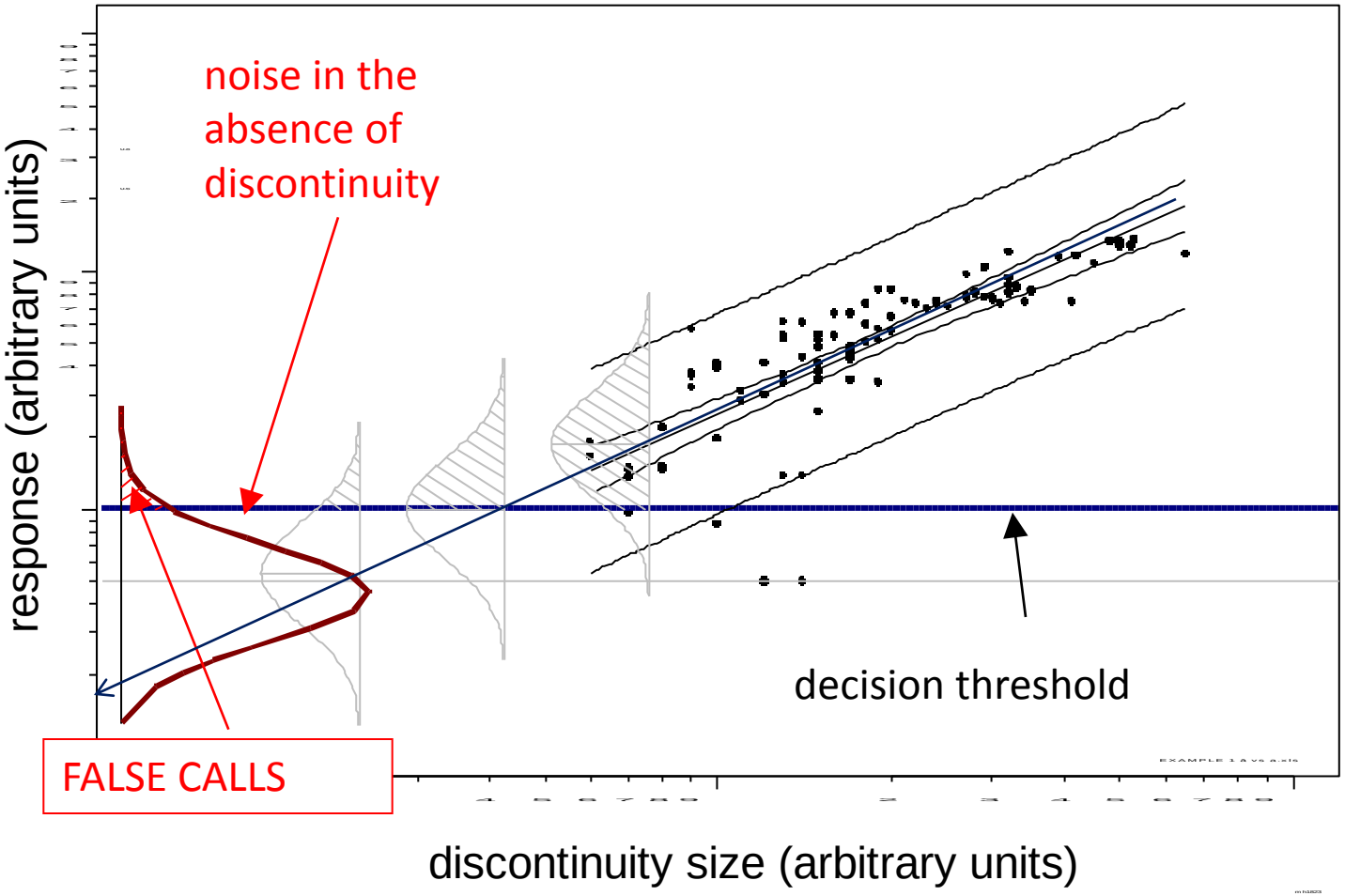
How to get POD? MAPOD!

- 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

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



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.

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- A fait accompli?
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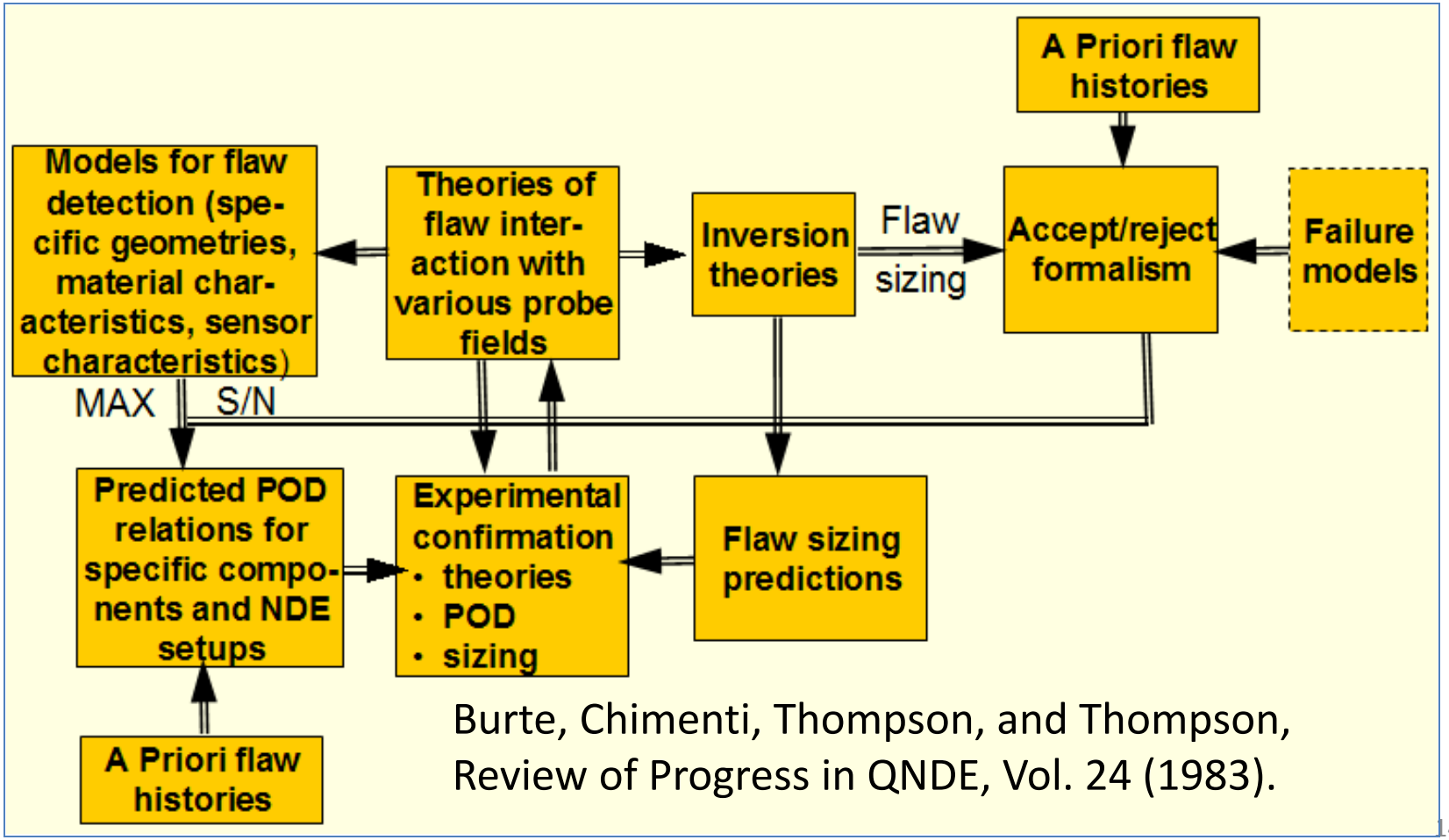
FREE DATABASE OF EVERYTHING*

- * 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!

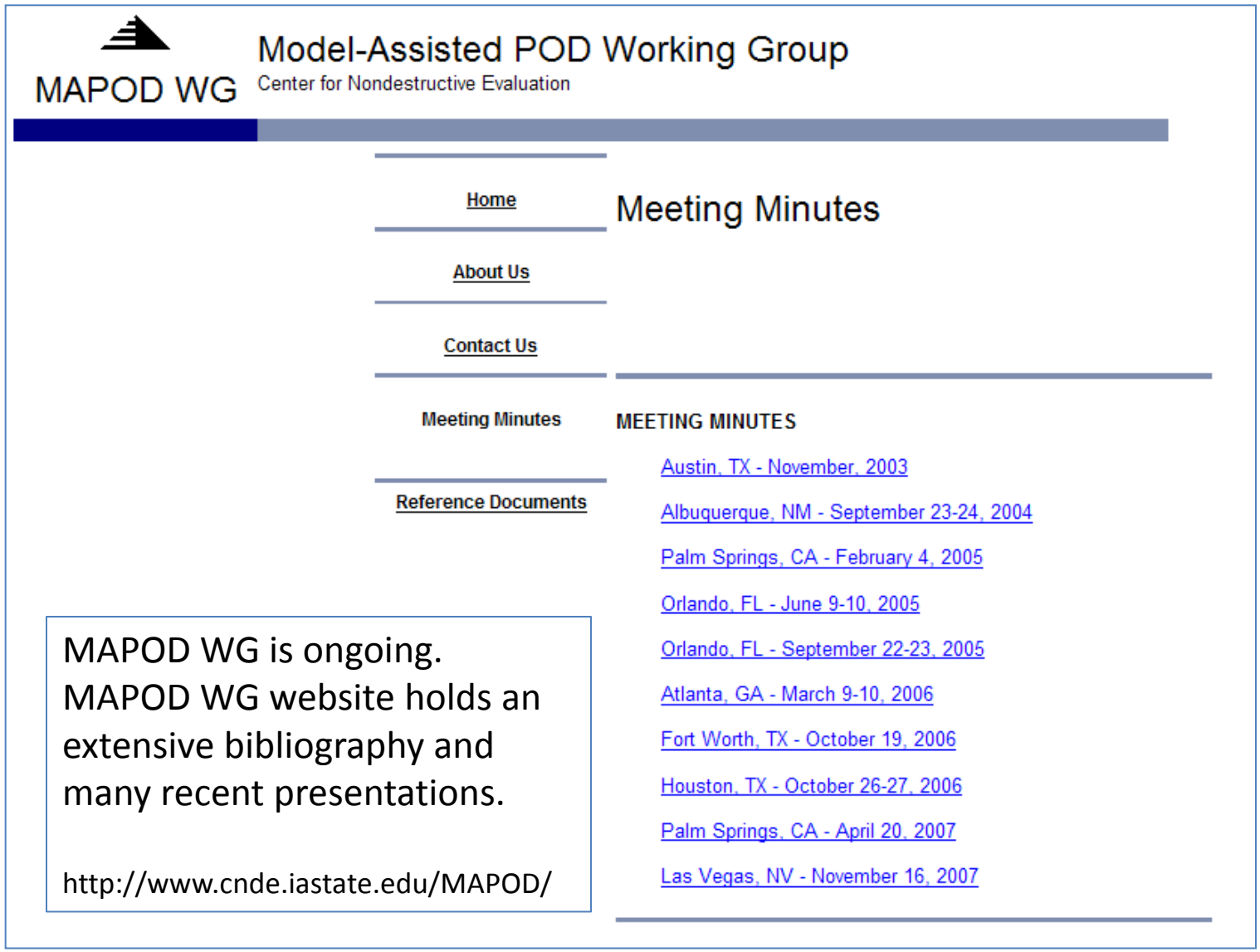
What has happened so far?

- Ideas have been around for some time.



Burte, Chimenti, Thompson, and Thompson, Review of Progress in QNDE, Vol. 24 (1983).

… so far?



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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The Many Paths to MAPOD

- 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.

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What might a MAPOD Handbook Look Like?

- 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…

What might a MAPOD Handbook Look Like?

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

What might a MAPOD Handbook Look Like?

- 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.

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What might a MAPOD Handbook Look Like?

- 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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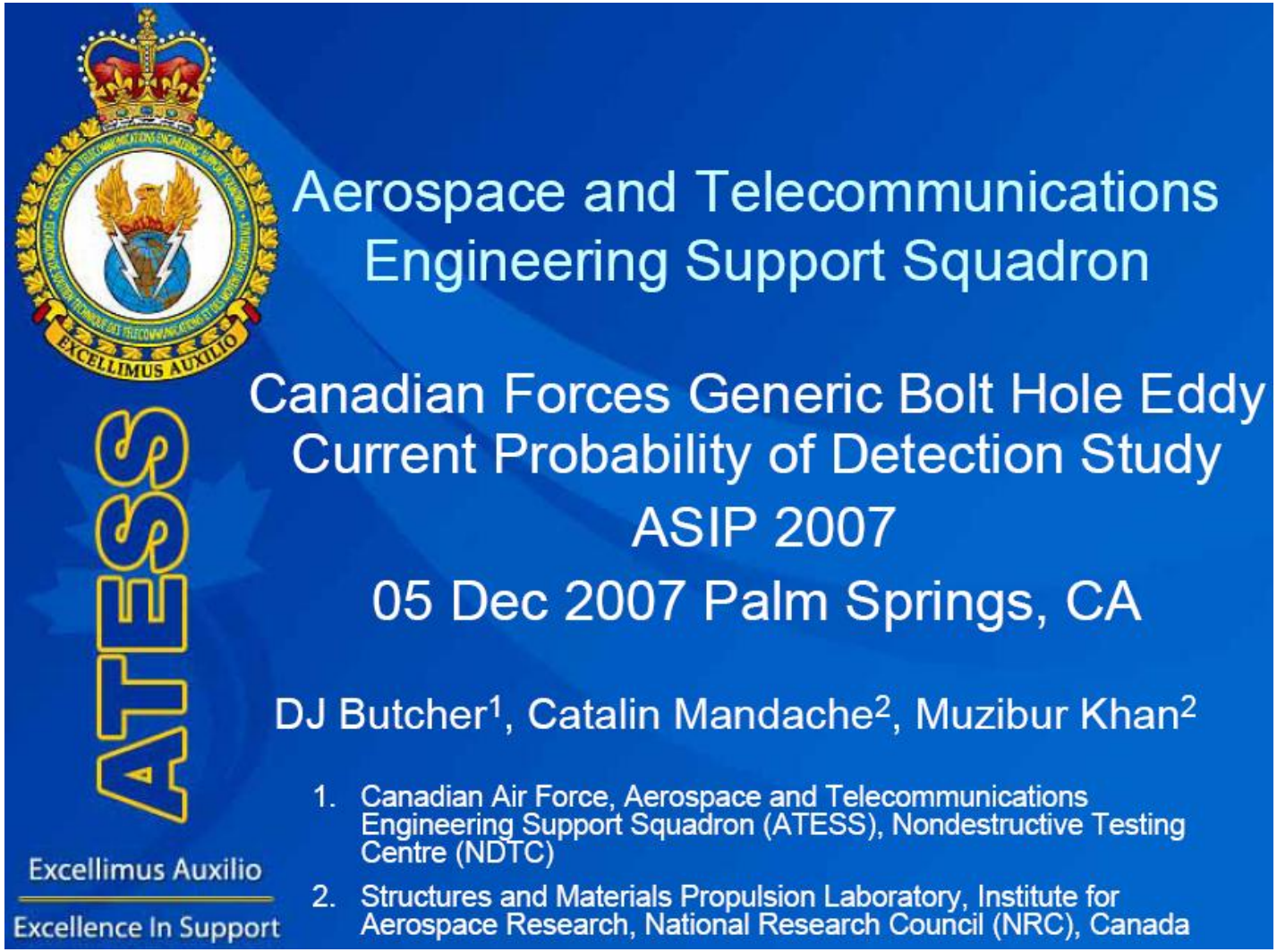
Examples

- 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


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
DJ Butcher[1], Catalin Mandache[2], Muzibur Khan[2]
1. Canadian Air Force, Aerospace and Telecommunications Engineering Support Squadron (ATESS), Nondestructive Testing Centre (NDTC)
2. Structures and Materials Propulsion Laboratory, Institute for Aerospace Research, National Research Council (NRC), Canada
ATESS
Excellimus Auxilio
Excellence In Support

Example 1

- β0, β1, ε derived empirically from traditional MIL-HDBK-1823 experiment
- $\varepsilon_{h.q.}$ (hole quality effect) also empirical, from a separate experiment.

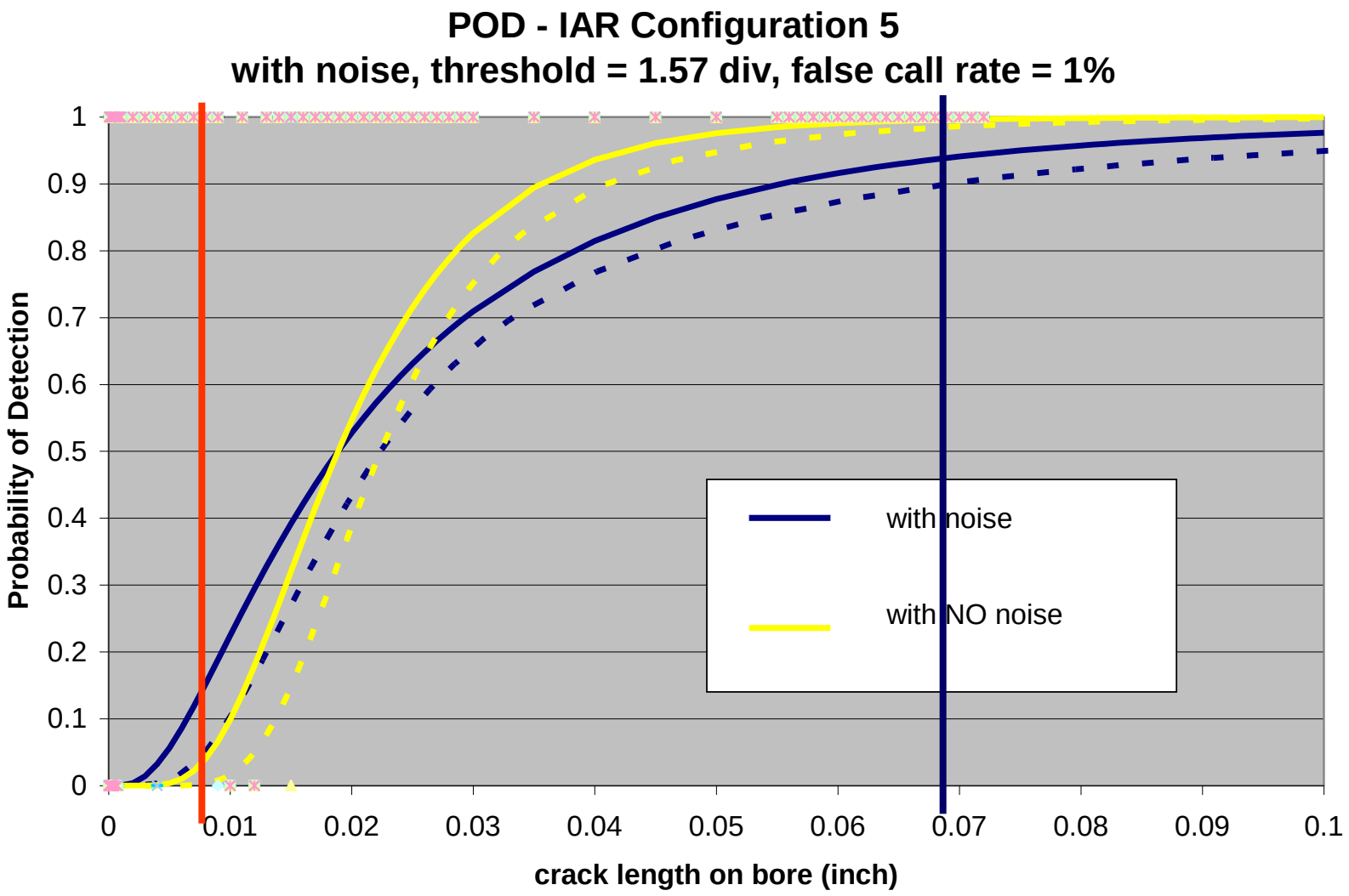
signal

crack size

random noise

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

Example 1 - POD



Moving on…

- 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: ahat 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 survreg() neglect a2	Analysis 1 survreg() use a1, a2	Analysis 2 glm()/MC use a1, a2	Analysis 3 BayesMCMC 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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Conclusions

- 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™.