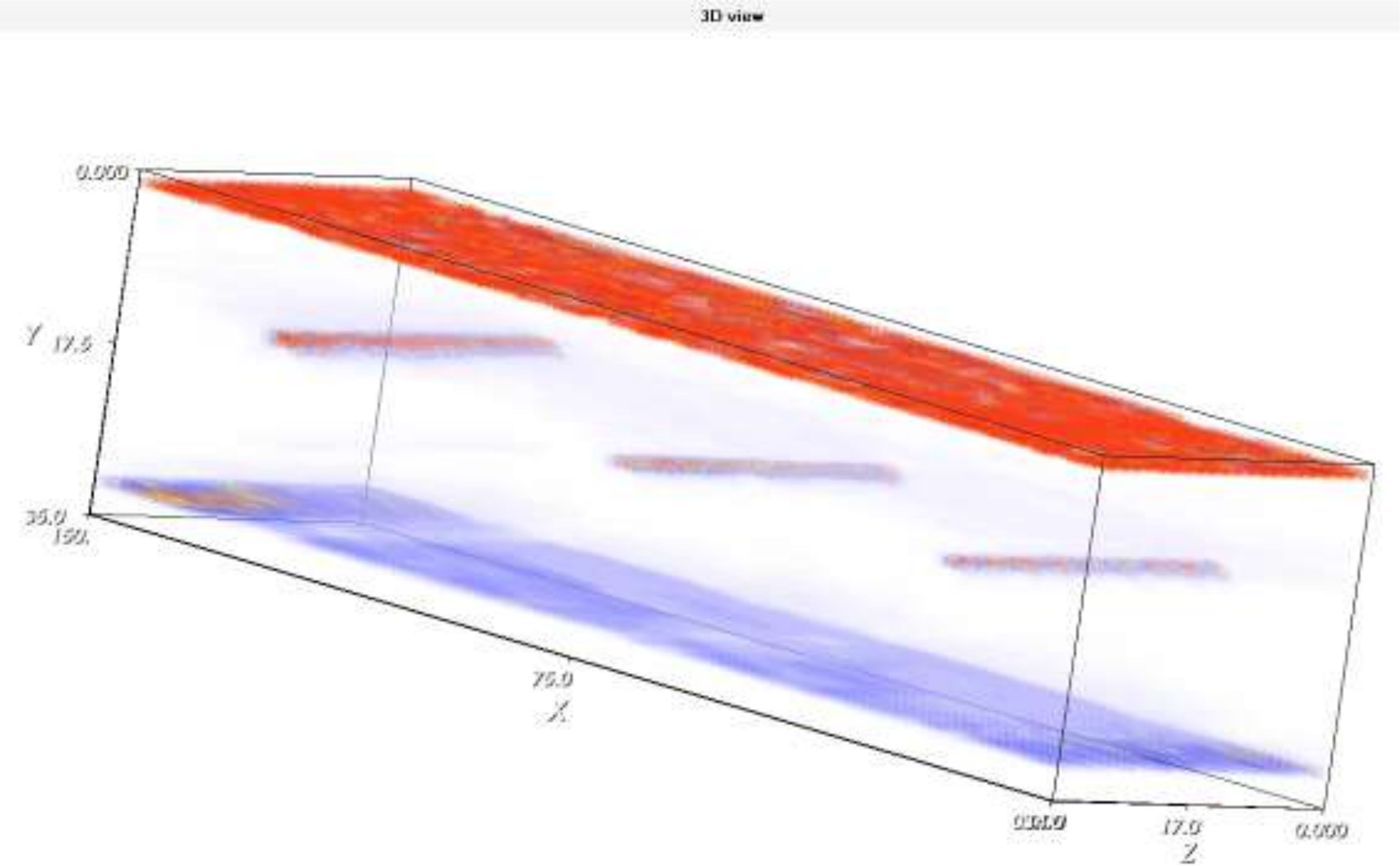
QUANTITATIVE NDT

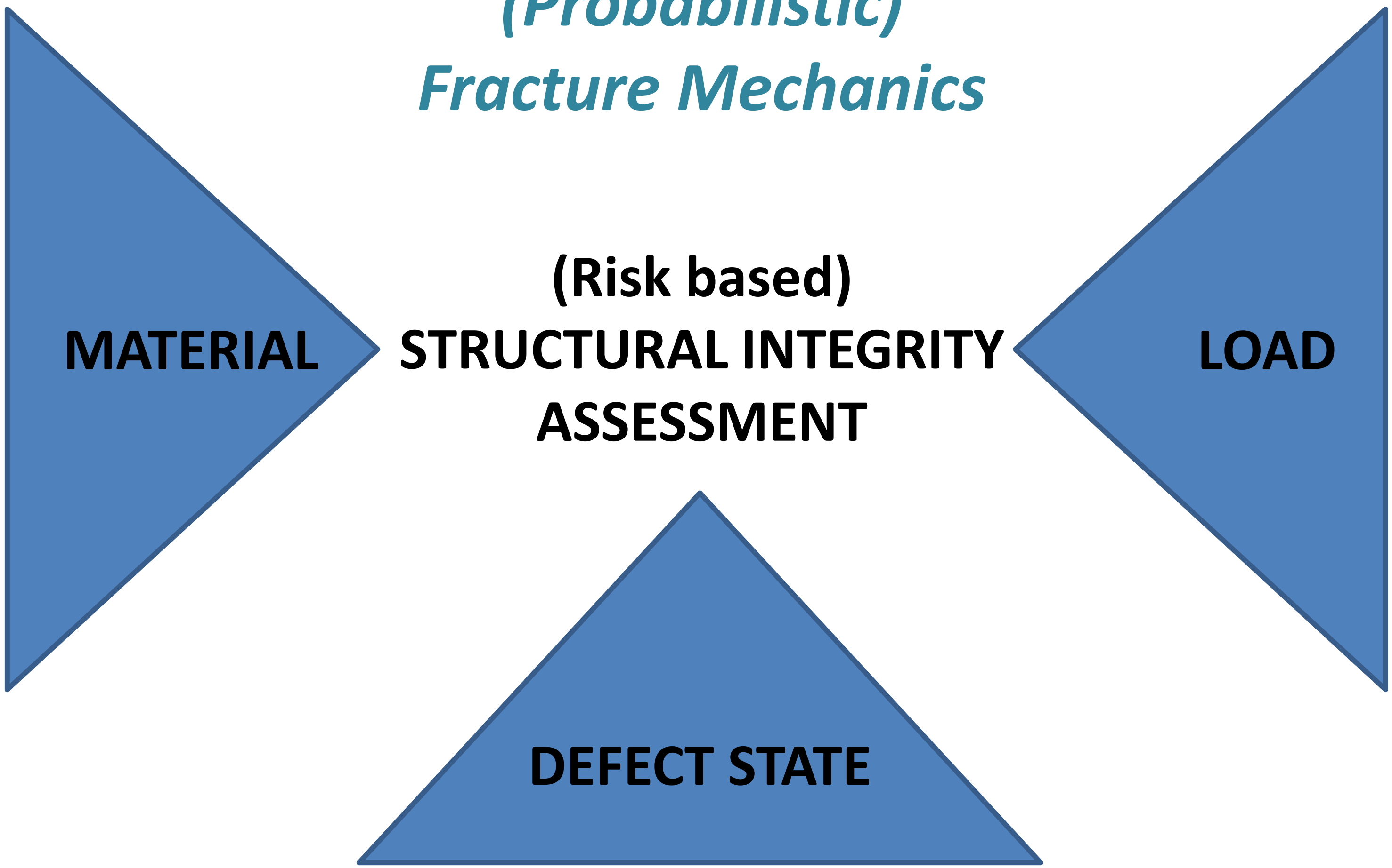


MATERIAL CHARACTERIZATION

4.	Mitigation Strategies – The world is never perfect
4.1.	Structure Design and NDT
4.2.	Application of NDT
4.3.	Limits of NDT
4.4.	Quantitative NDT
4.5.	Material Characterization
4.6.	Case Study – Inspection by Cause

MOTIVATION

(Probabilistic)
Fracture Mechanics

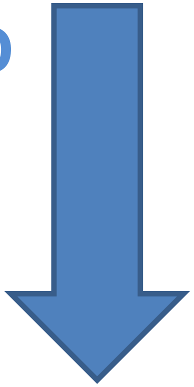


DEFECT STATE EVALUATION

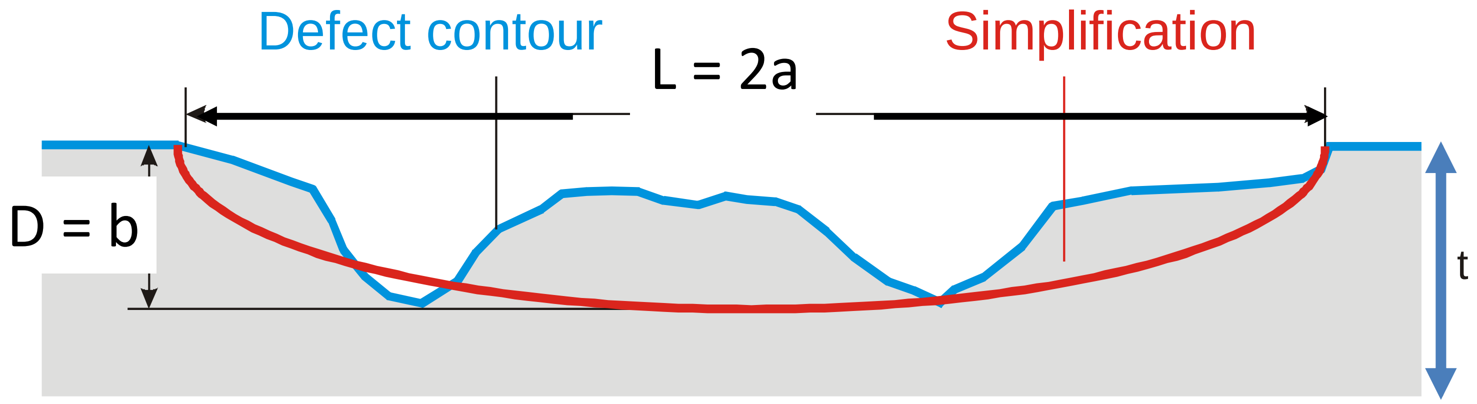
NDT DATA

FEATURE BASED

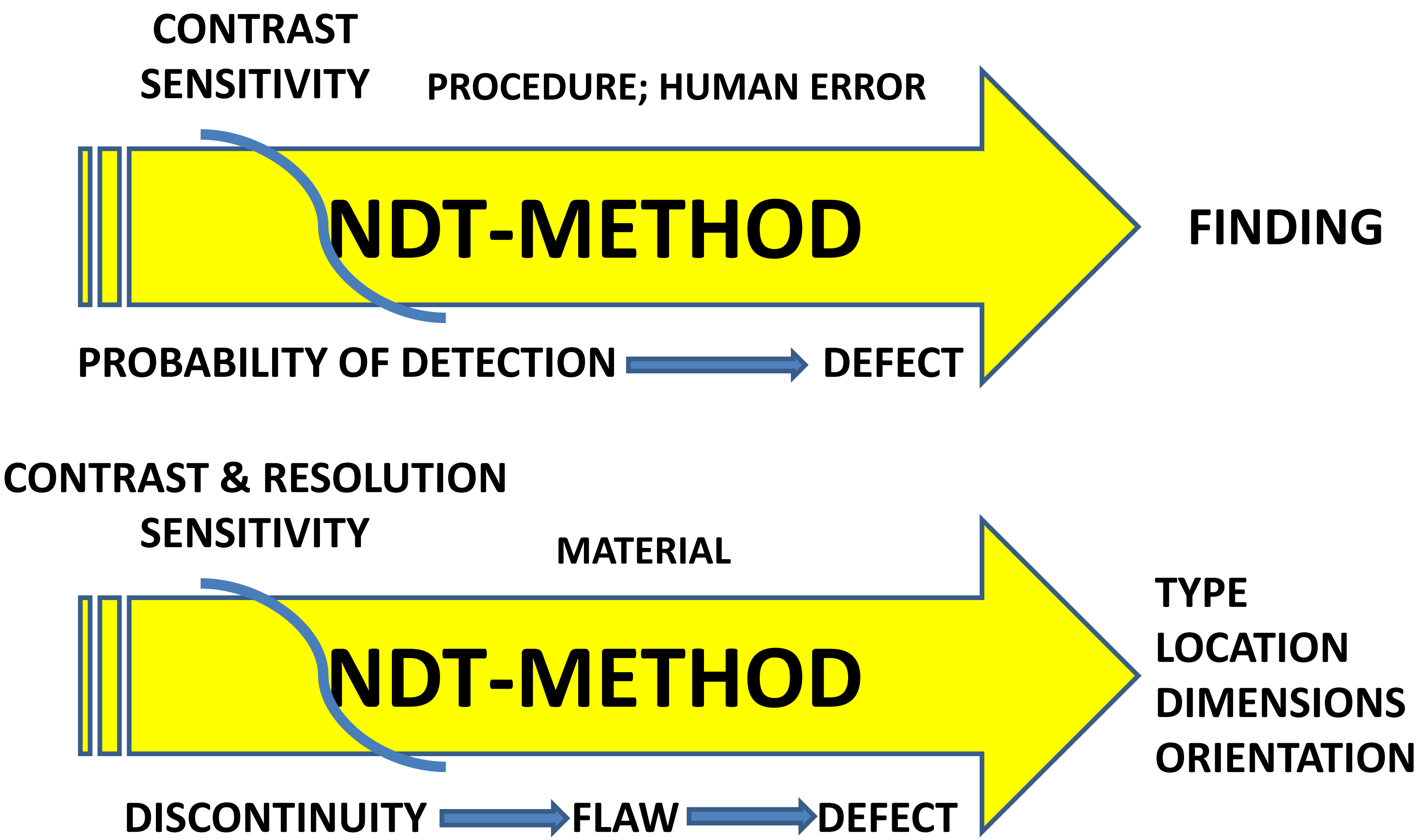
IMAGE BASED



FRACTURE MECHANIC CRACK



DEFECT STATE EVALUATION



DEFECT STATE EVALUATION

CONSERVATIVE PROCEDURE:
Max. Stress Concentration

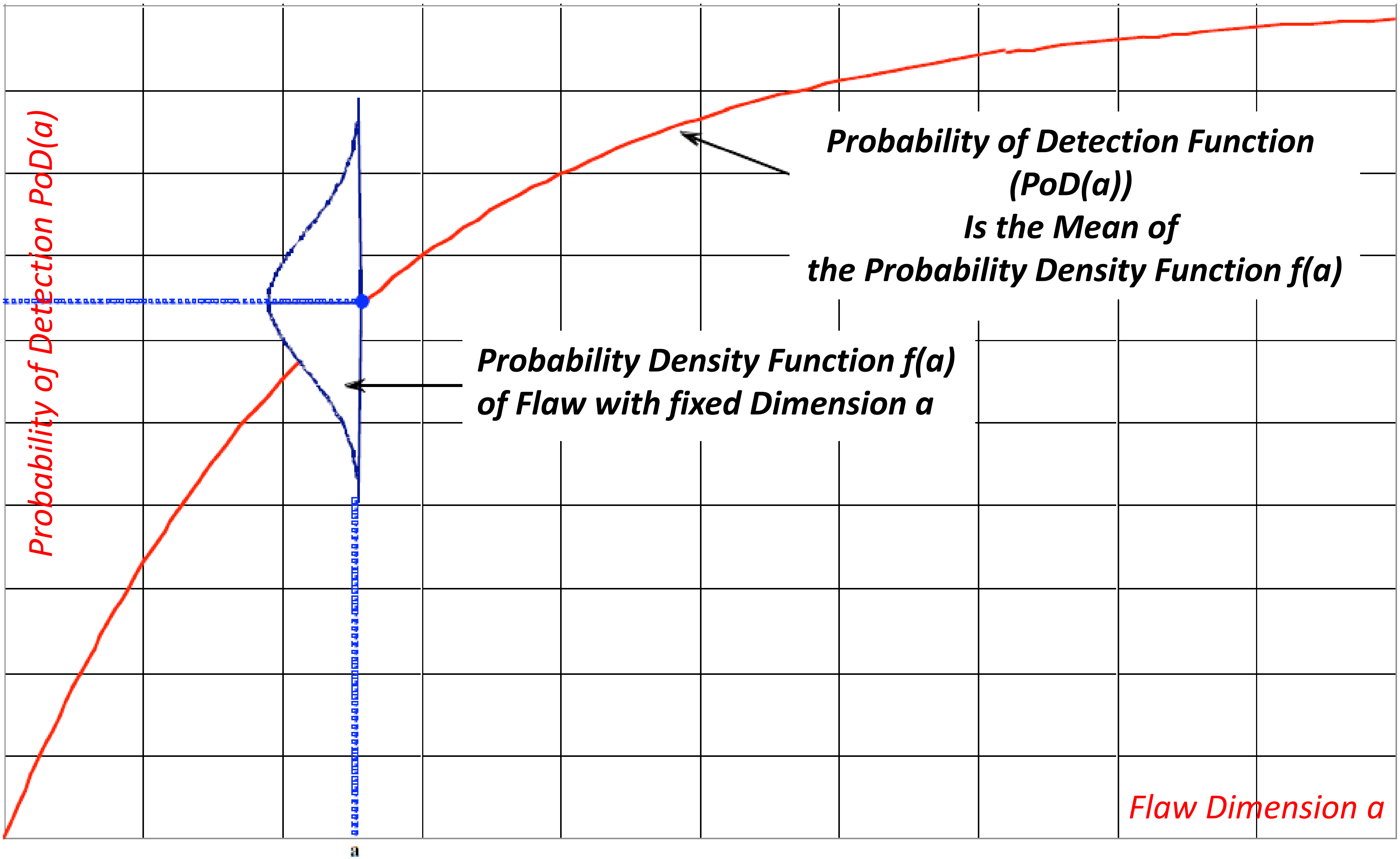
CRACK-LIKE FLAW

CONVERSION

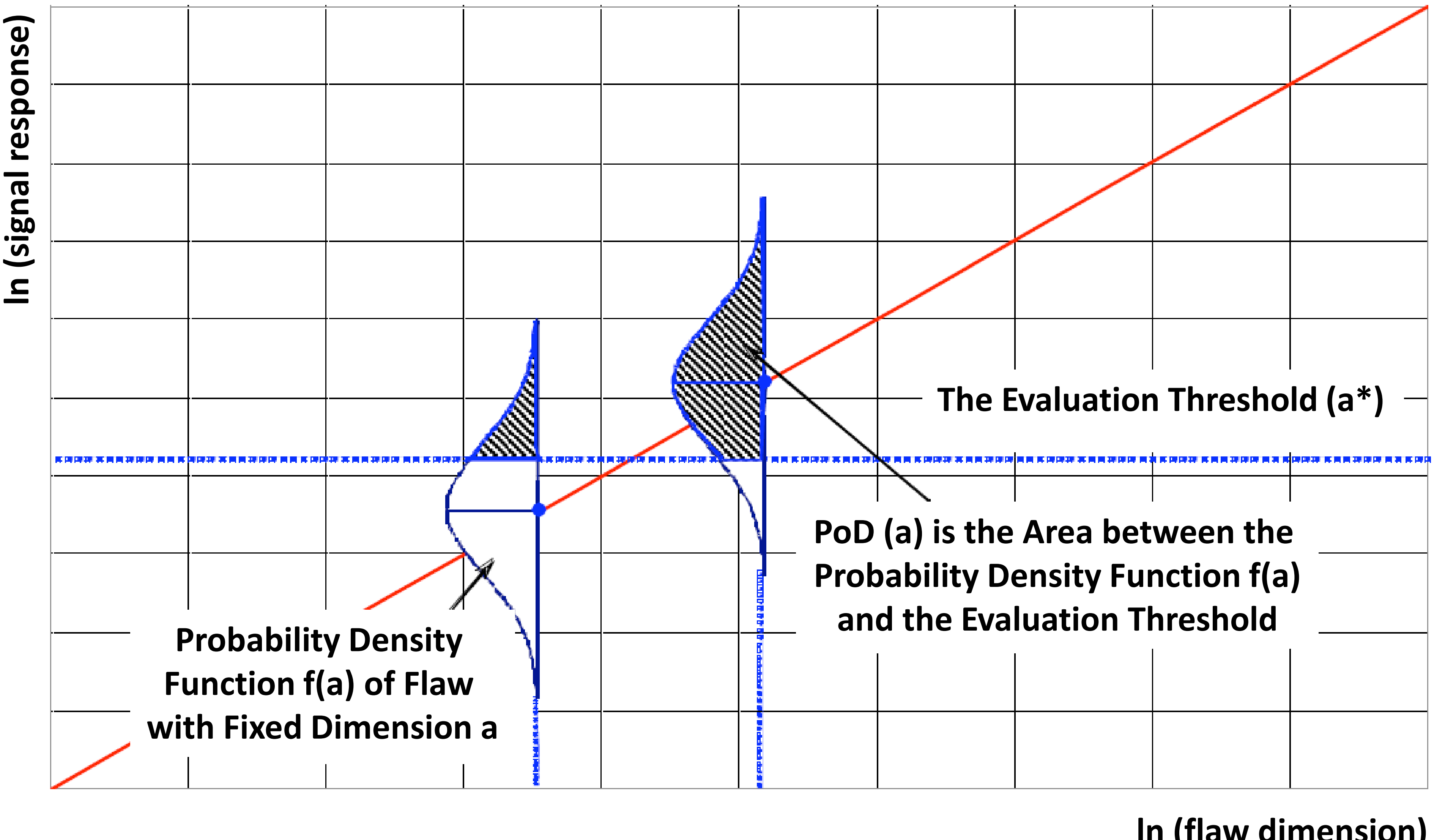
FM CRACK LOCATION

FLAW EDGES ASSUMED INFINITELY SHARP

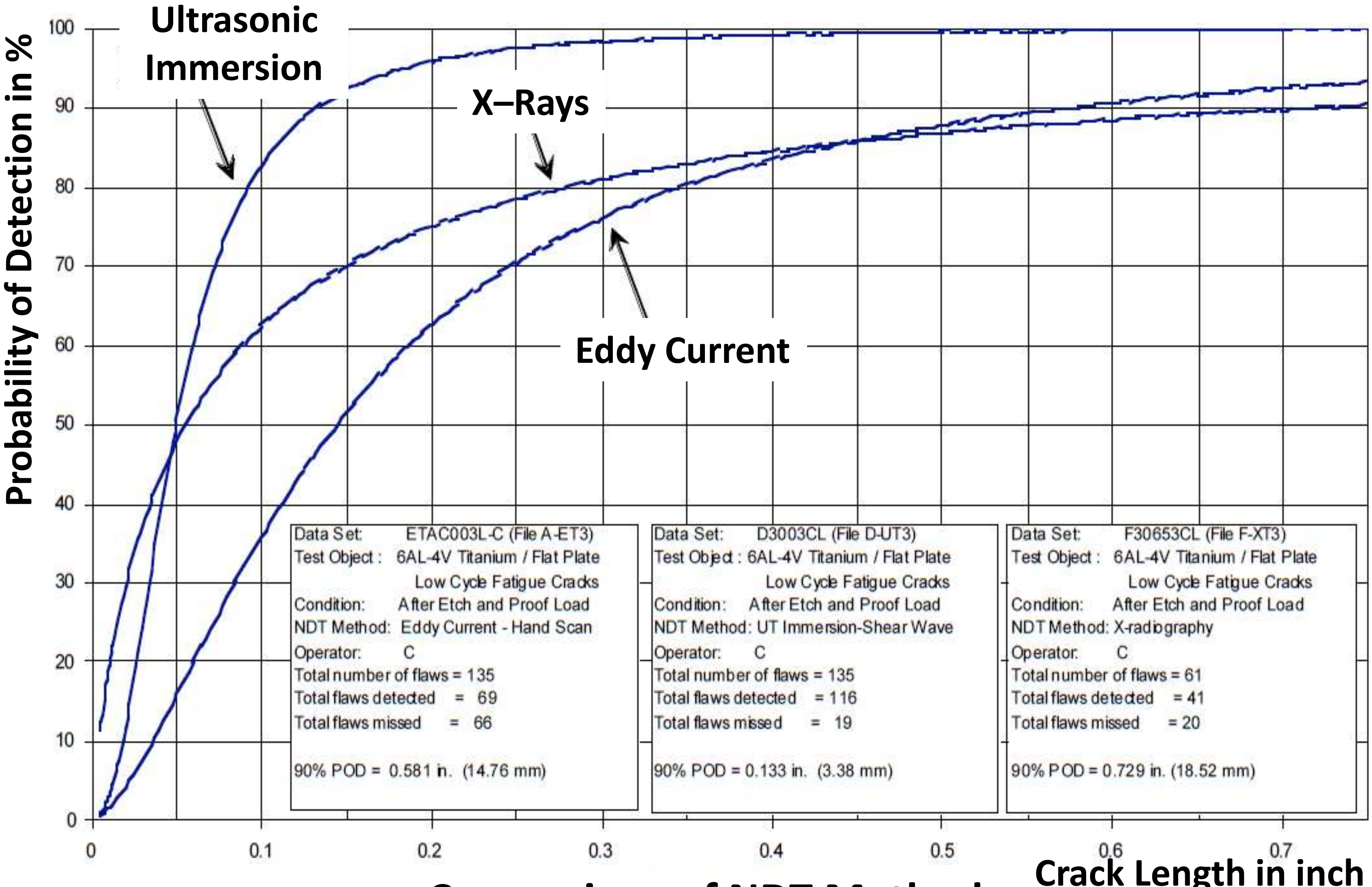
PROBABILITY of DETECTION



PROBABILITY of DETECTION

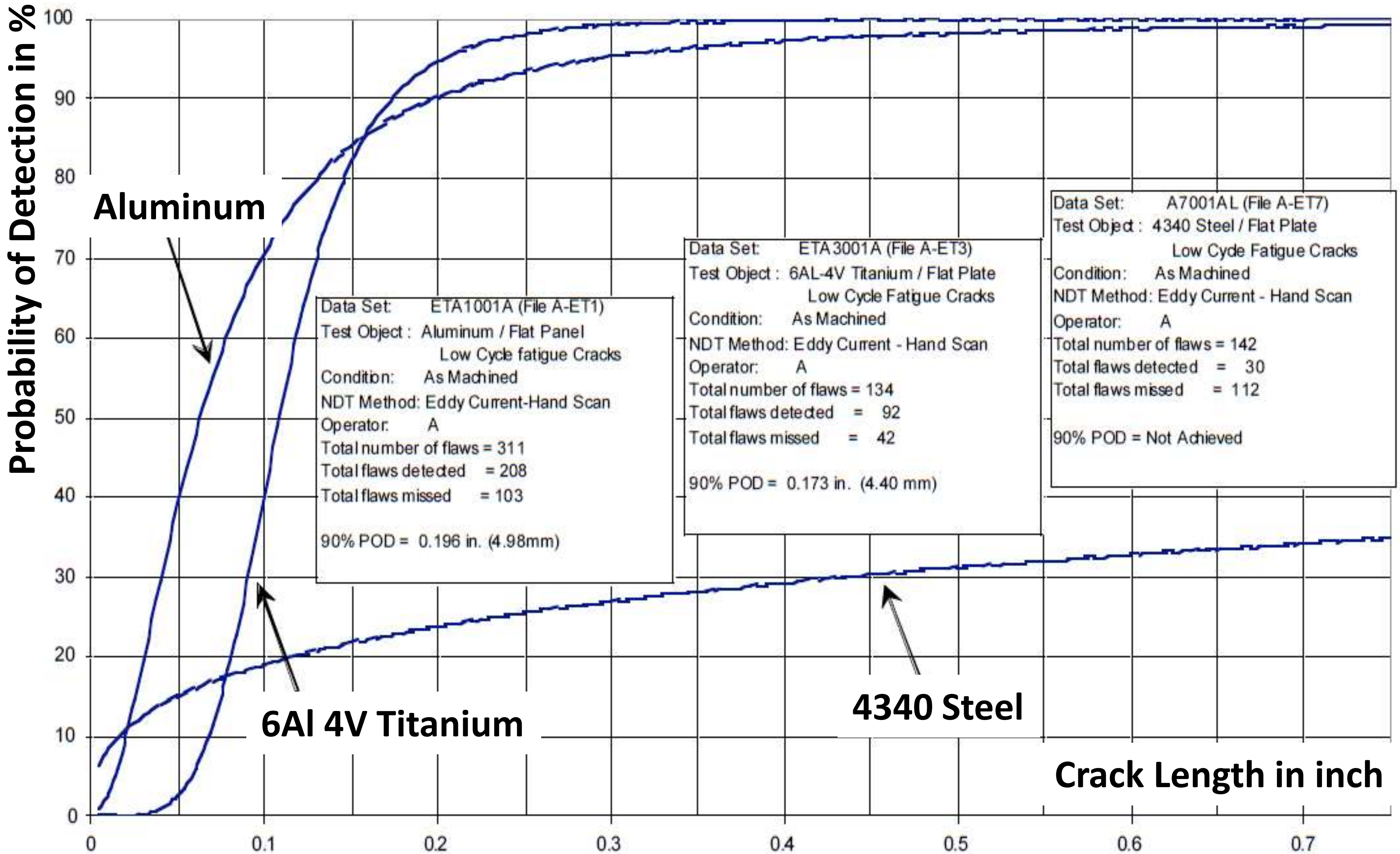


PROBABIBILITY of DETECTION



Comparison of NDT Methods

PROBABIBILITY of DETECTION



PoD by EC Inspection of Different Materials with same Flaws

(Rummel)

Comment on the Use of PoD

The design, operation, maintenance, life cycle and risk analyses changed dramatically with the development, application and incorporation of fracture mechanics in engineering requirements, engineering practices and engineering systems management. Those engineering changes increased demands and a revolution in NDT requirements, practices and technology advancement.

The Probability of Detection (POD) metric was developed to provide a quantitative assessment of NDT detection capabilities and was focused on the smallest reliably detectable flaw. The PoD holds only for a well specified flaw type, for a specific component, and for a well written inspection procedure. Nevertheless, there are still remaining uncertainties. Unfortunately, POD is often misinterpreted as a primary measure of the reliability of NDT procedures.

(Rummel)

Comment on the Use of PoD

Nevertheless:

Probability of detection (POD) tests are a standard way to evaluate a nondestructive testing technique in a given set of circumstances, for example: "What is the POD of lack of fusion flaws in pipe welds using manual ultrasonic testing?"

Guidelines for correct application of statistical methods to POD tests can be found in ASTM E2862 Standard Practice for Probability of Detection Analysis for Hit/Miss Data and MIL-HDBK-1823A Nondestructive Evaluation System Reliability Assessment, from the U.S. Department of Defense Handbook.

PROBABILITY OF DETECTION

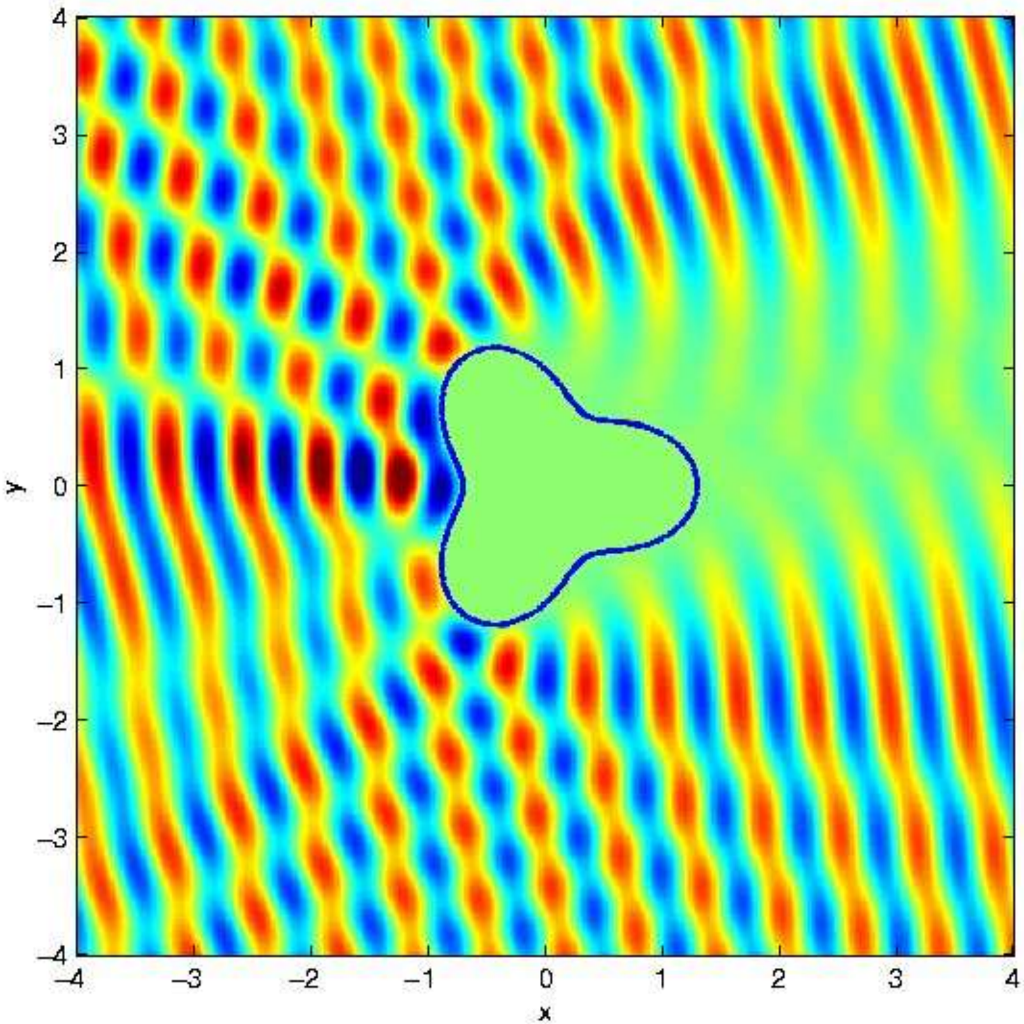
PoD (planar flaws) = f(Performance) X f(Contrast)

VALIDATION

f(Performance)	f(Contrast)
HUMAN ERROR	FLAWS & MATERIAL
AUTOMATION	NDT METHOD
COVERAGE	SENSITIVITY

PROBABILITY of DETECTION

You may be mistaken – there are many reasons for missing a flaw



Rapid progress in computer power and numerical algorithms in recent decades has revolutionized science and technology.

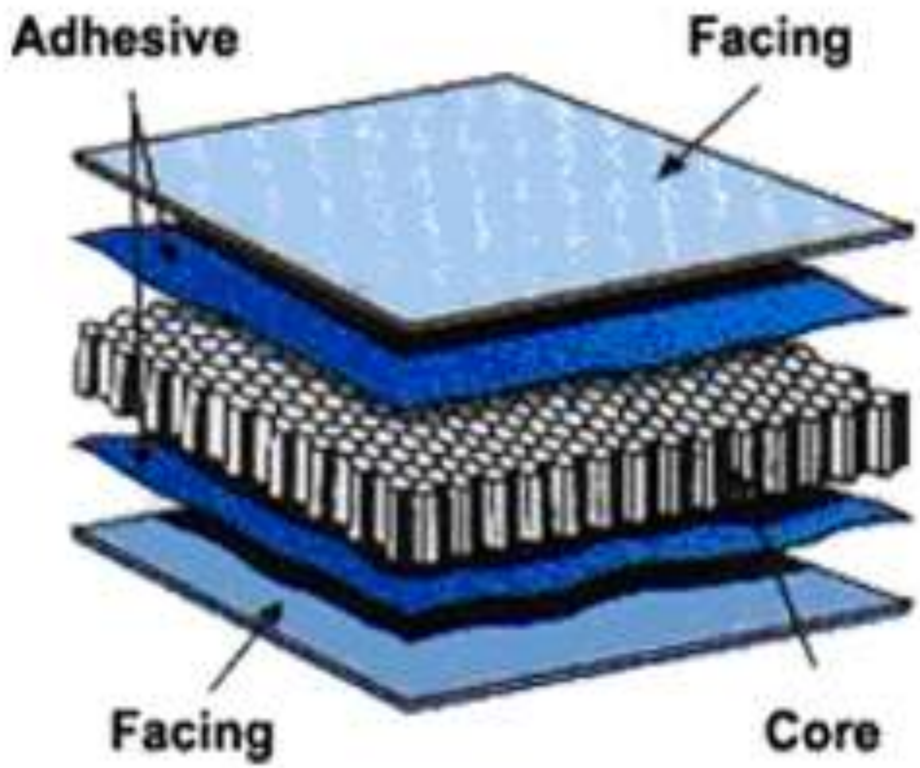
The Laplace equation (describing steady-state diffusion, heat flow, electrostatics) and Helmholtz equation (linear waves, acoustics, electromagnetics, optics, quantum) are linear PDE boundary value problems, ubiquitous in modeling the real world.

Alex Barnett, 2012

PROBABILITY of DETECTION

You may be mistaken – there are many reasons for missing a flaw

Sandwich Panel



Hydrogen Blistering

PROBABIBILITY of DETECTION

You may be mistaken – there are many reasons for missing a flaw

BETATRON INSPECTION

OMAN

PROBABILITY of DETECTION

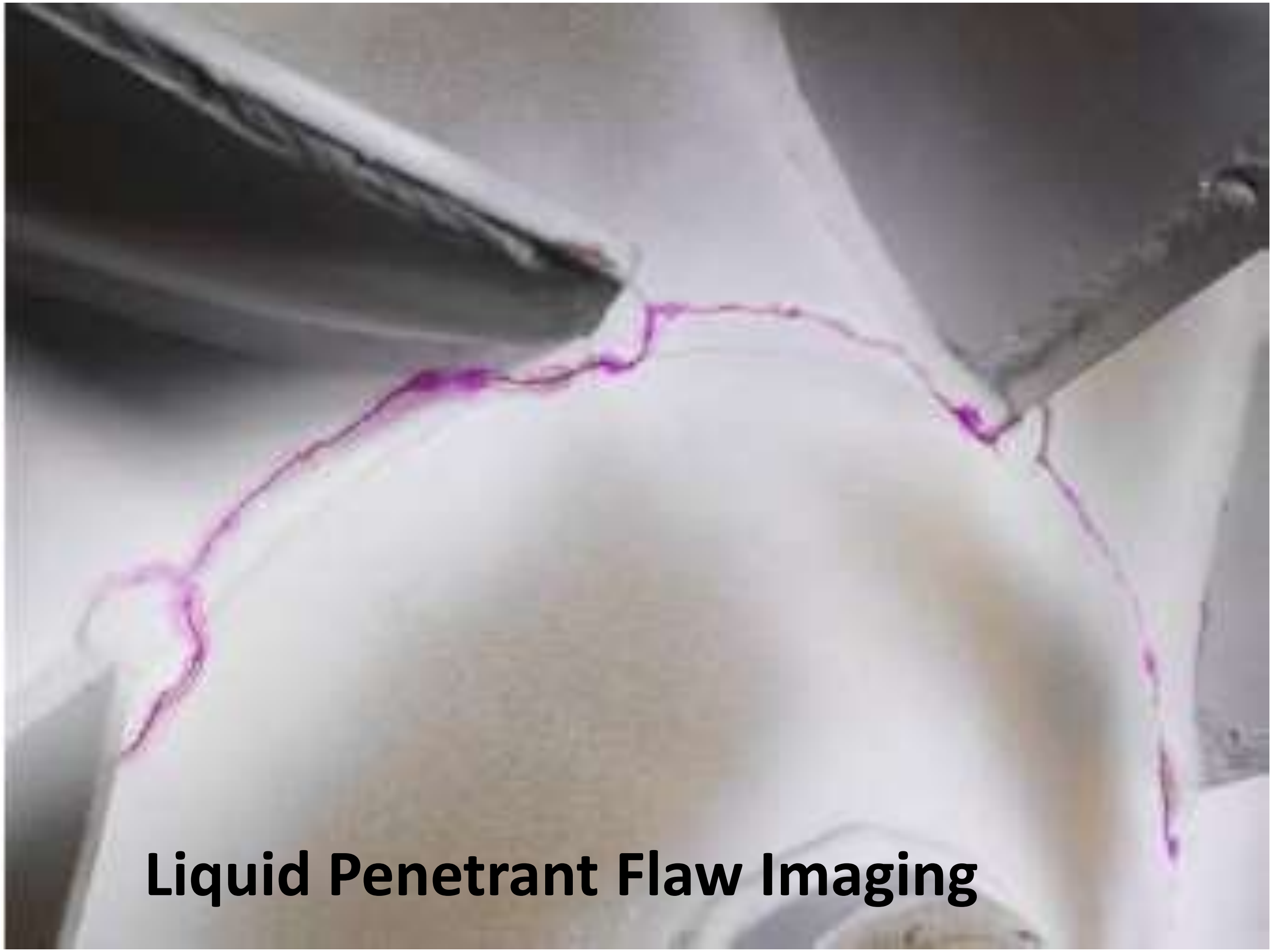
You may be mistaken – there are many reasons for missing a flaw

Reactor Core Plate

FLAW DETECTION & EVALUATION

FLAW IMAGING	FEATURE CORRELATION
FULL IMAGE (3D)	REFERENCE FLAW
PARTIAL IMAGE	FEATURE SPACE

PARTIAL FLAW IMAGING



Surface Breaking Cracks

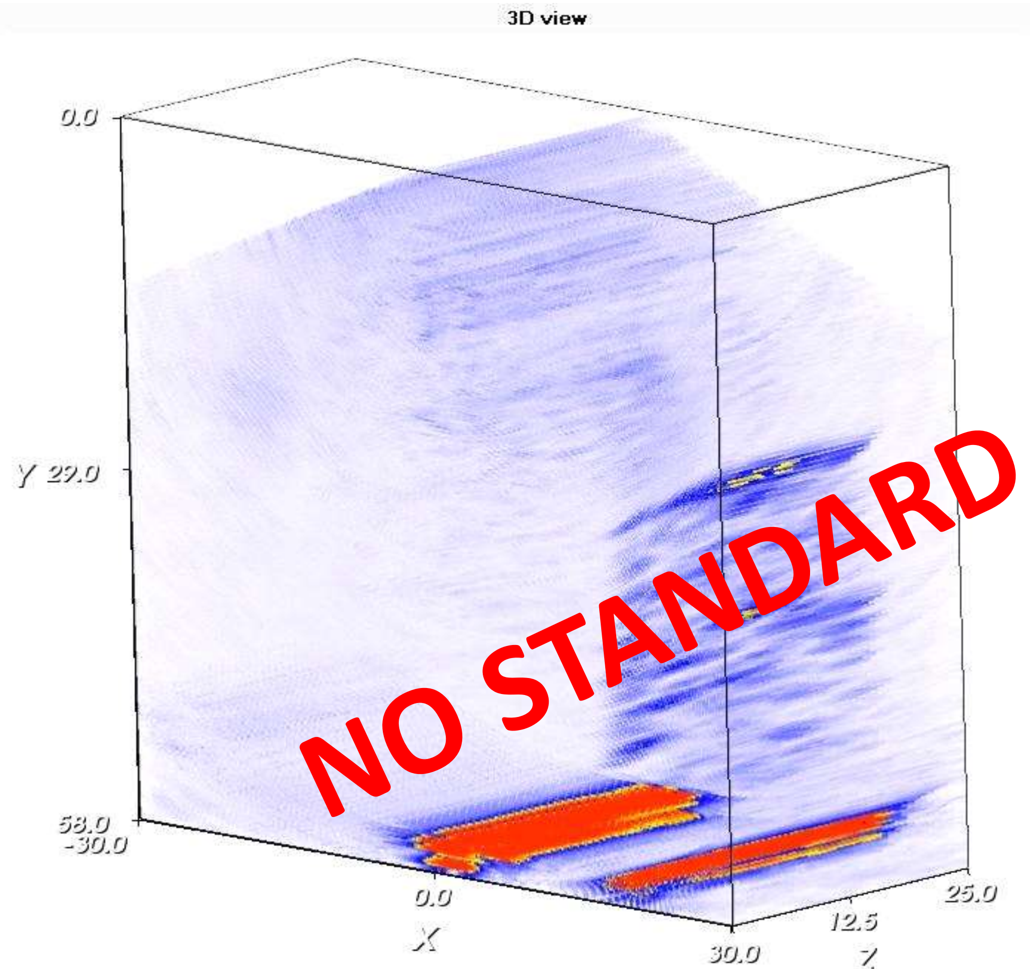
Crack Length: visualized
Crack depth: unknown

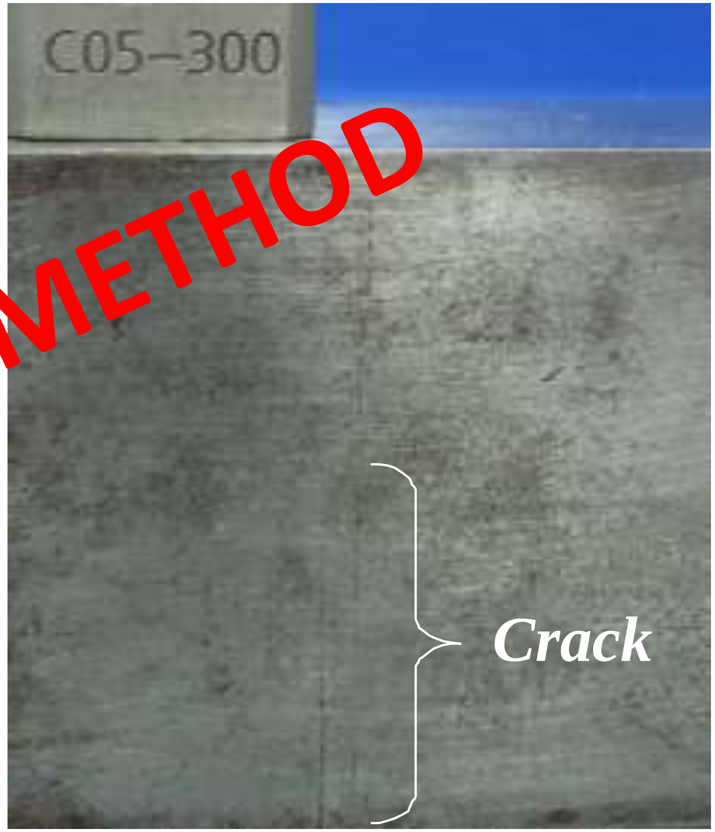
FM Crack: 2a
b: other methods

3-D FLAW IMAGING

X-RAY Computed Laminography:
Transverse Crack in a Aluminum HV Weld

3-D FLAW IMAGING



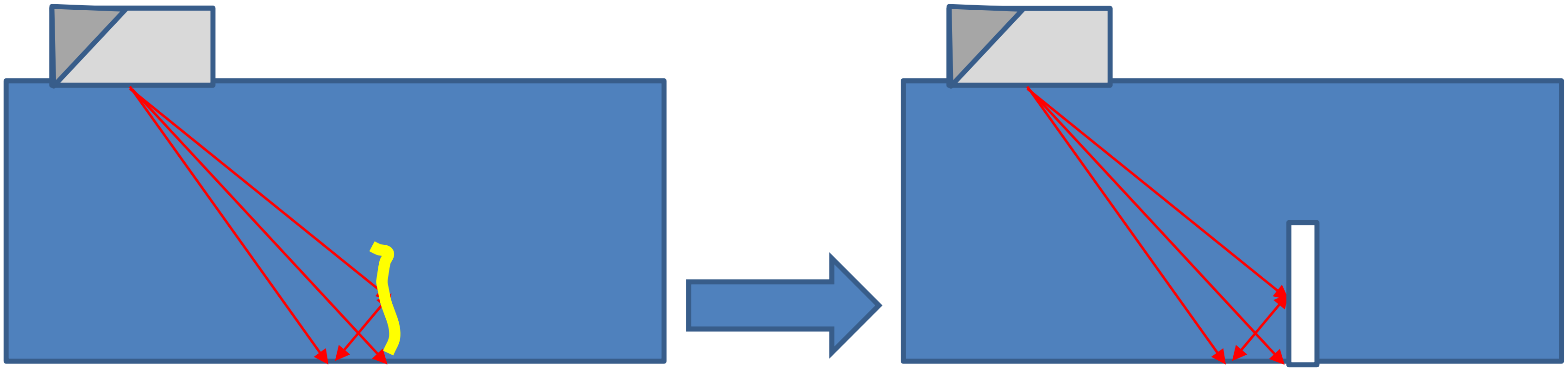


UT Computed Fatigue Crack Imaging

5 MHz linear array transducer; 1 transducer position; Code: Migration

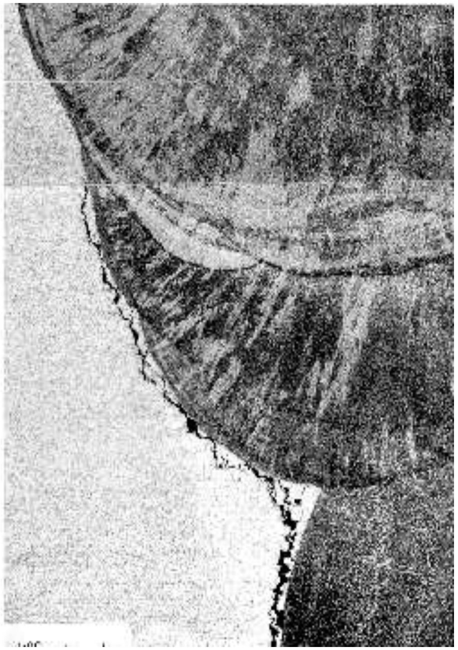
FLAW DETECTION & EVALUATION

FEATURE CORRELATION - REFERENCE FLAWS



The acoustic cat eye effect

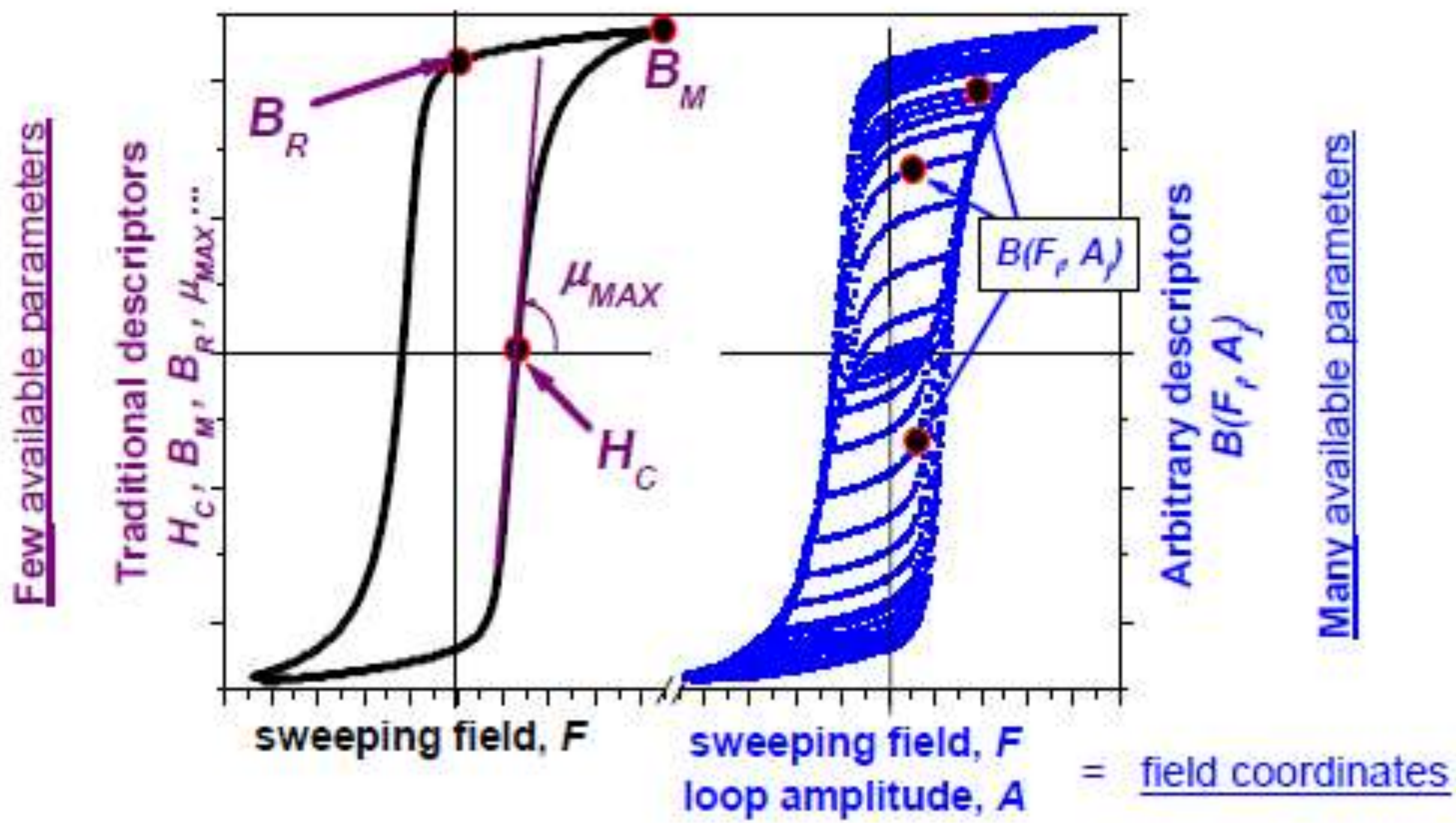
Ultrasonic pulse reflection at a notch serves as a reference for crack detection and flaw evaluation



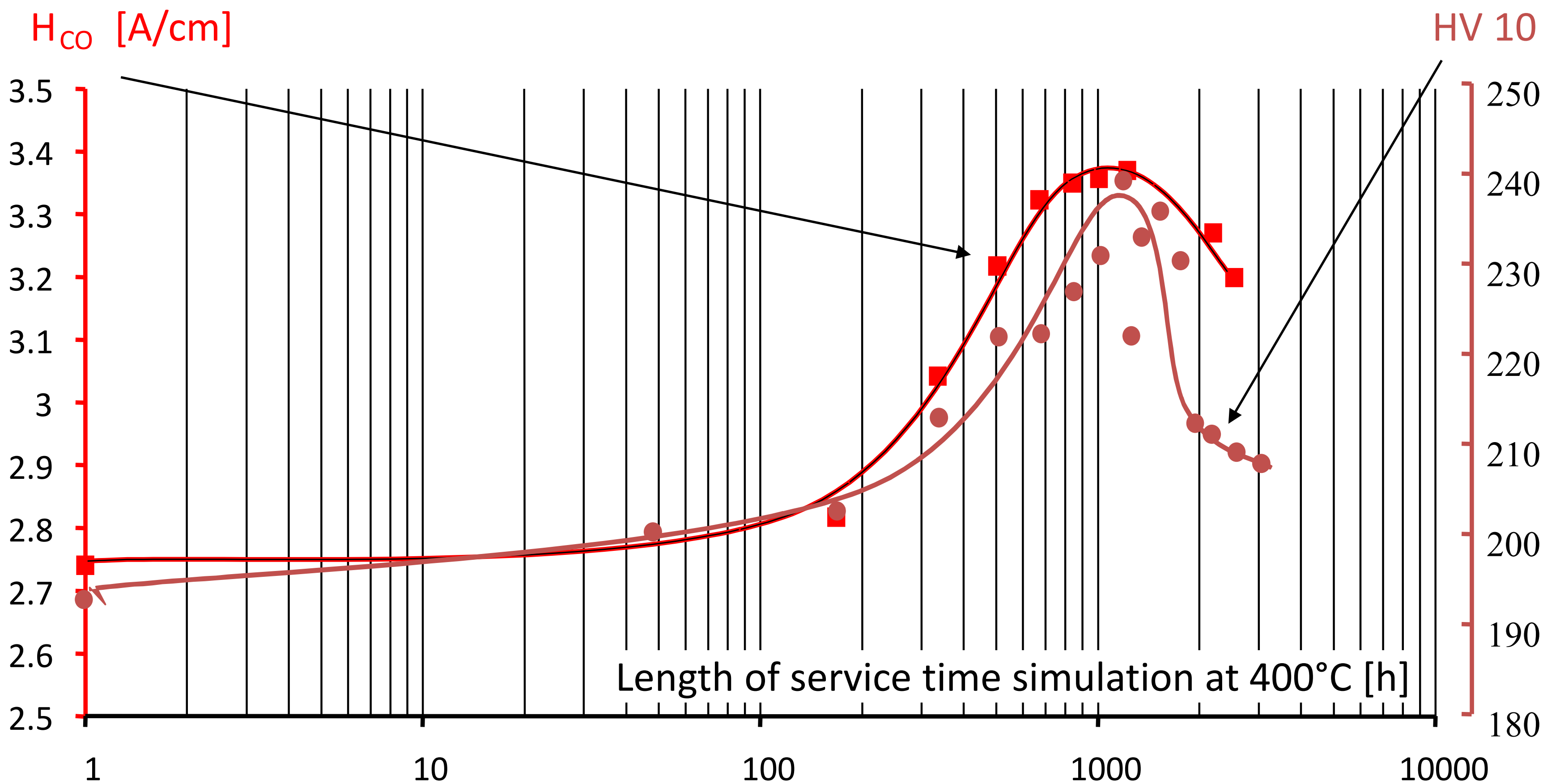
That's not always a good procedure

FEATURE SPACE CORRELATION

MAT A MULTIPLE PARAMETER OPTIMIZATION APPROACH

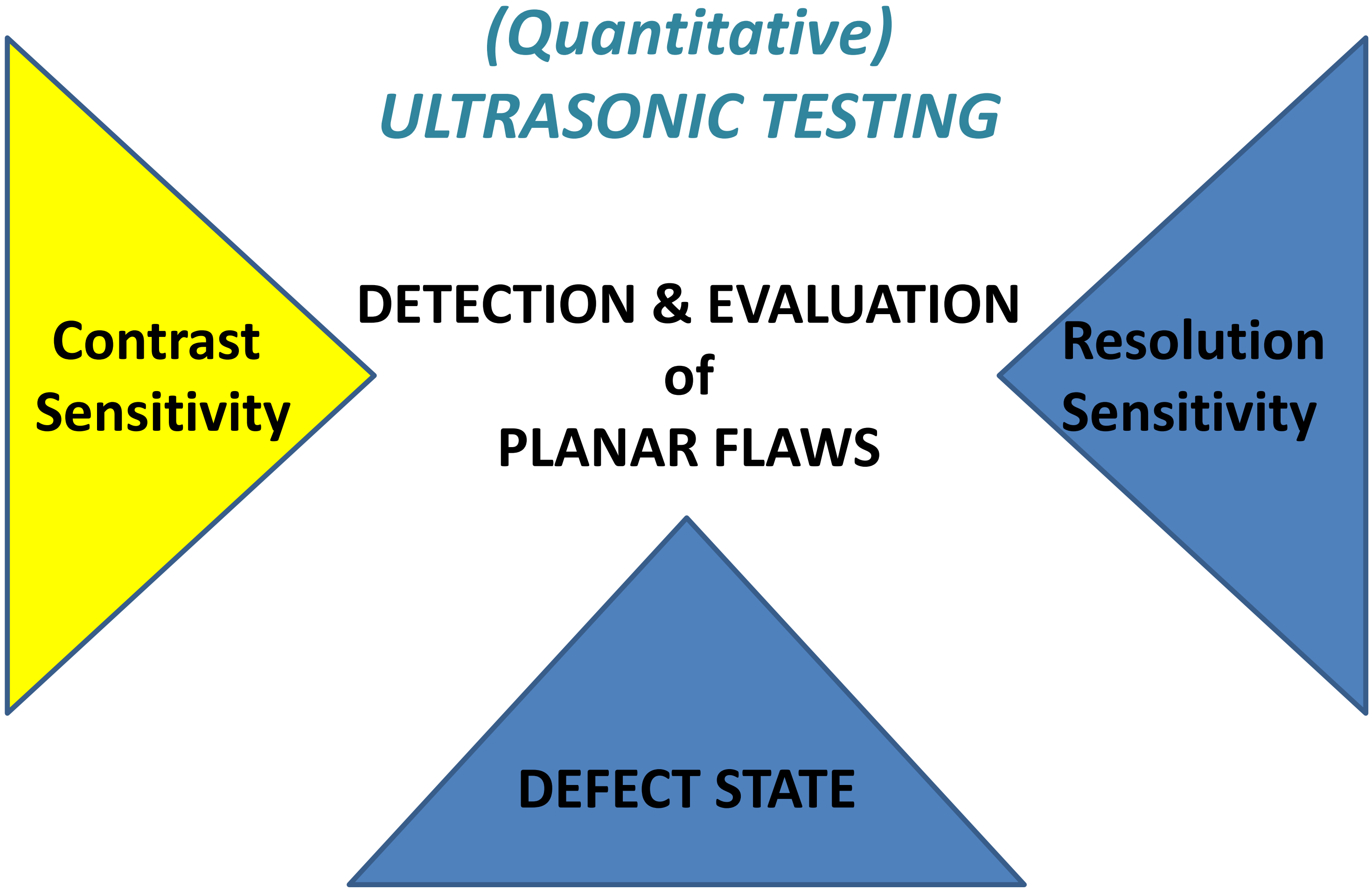


FEATURE SPACE CORRELATION



Analogy Between Mechanical and Magnetic Hardness

A CASE CONSIDERATION – ULTRASONIC TESTING



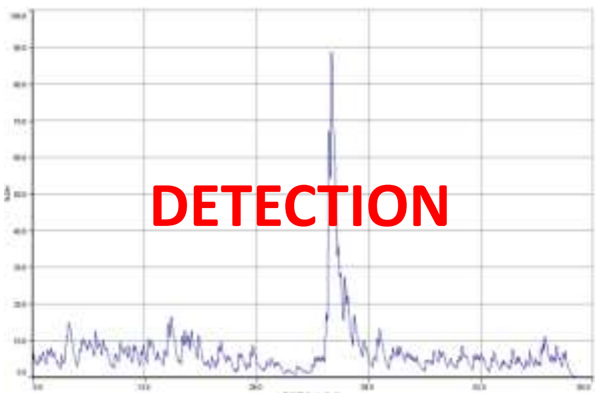
Advanced UT Systems

? WHY ULTRASONIC TESTING ?

BEST CONTRAST SENSITIVITY FOR PLANAR DEFECTS (Crack Detection)

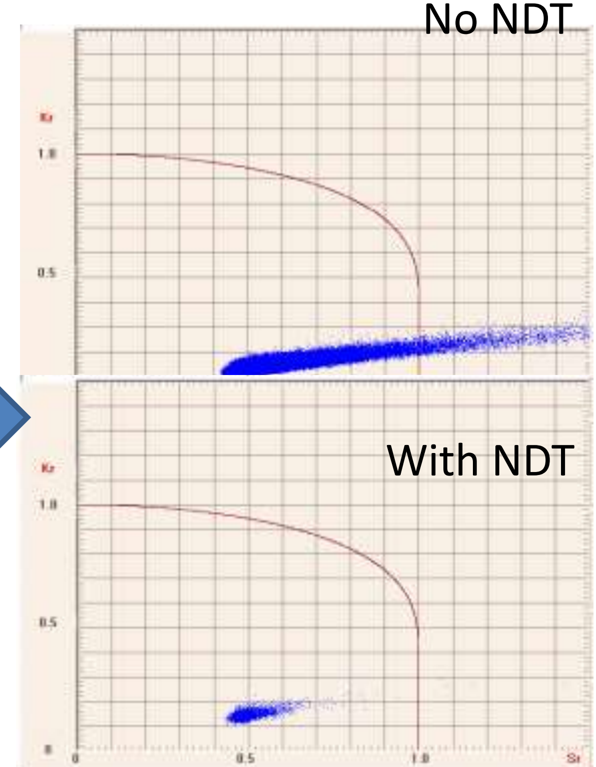
POOR FLAW IMAGING (Crack Sizing)

QUT
- QUANTITATIVE ULTRASONIC TESTING -
A Preventive Action for the Integrity of Structures under Load



DETECTION

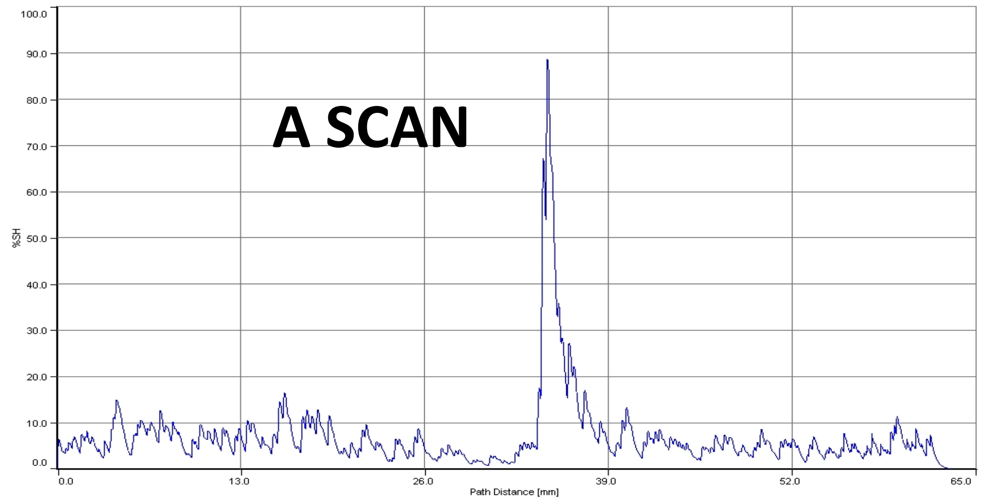
SIZING ?



POD
(Probability of Detection)

A CASE CONSIDERATION – ULTRASONIC TESTING

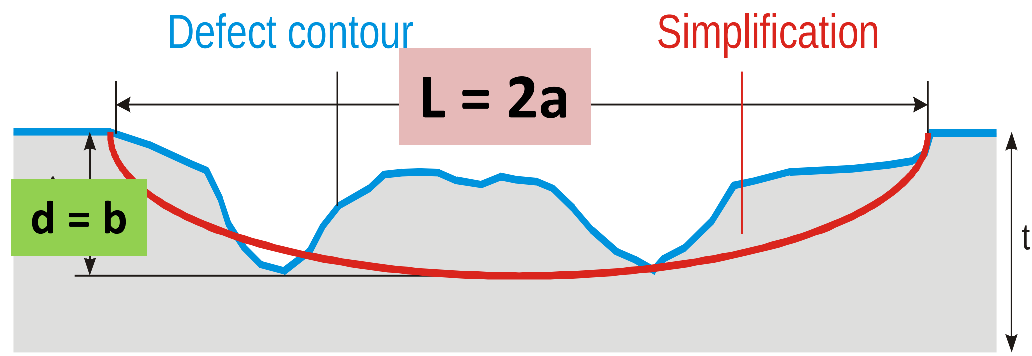
45°/4 MHz A-scan
ID Crack Signal



STATE OF ENGINEERING

STATE OF PHYSICS

FRACTURE MECHANIC
MODEL CRACK

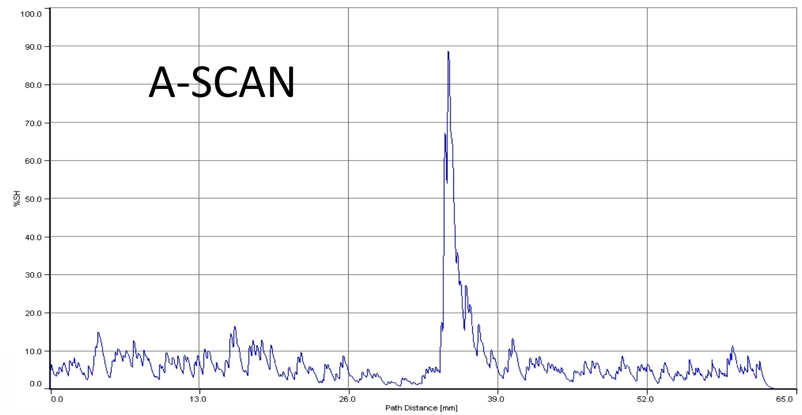


In general: a poor correlation

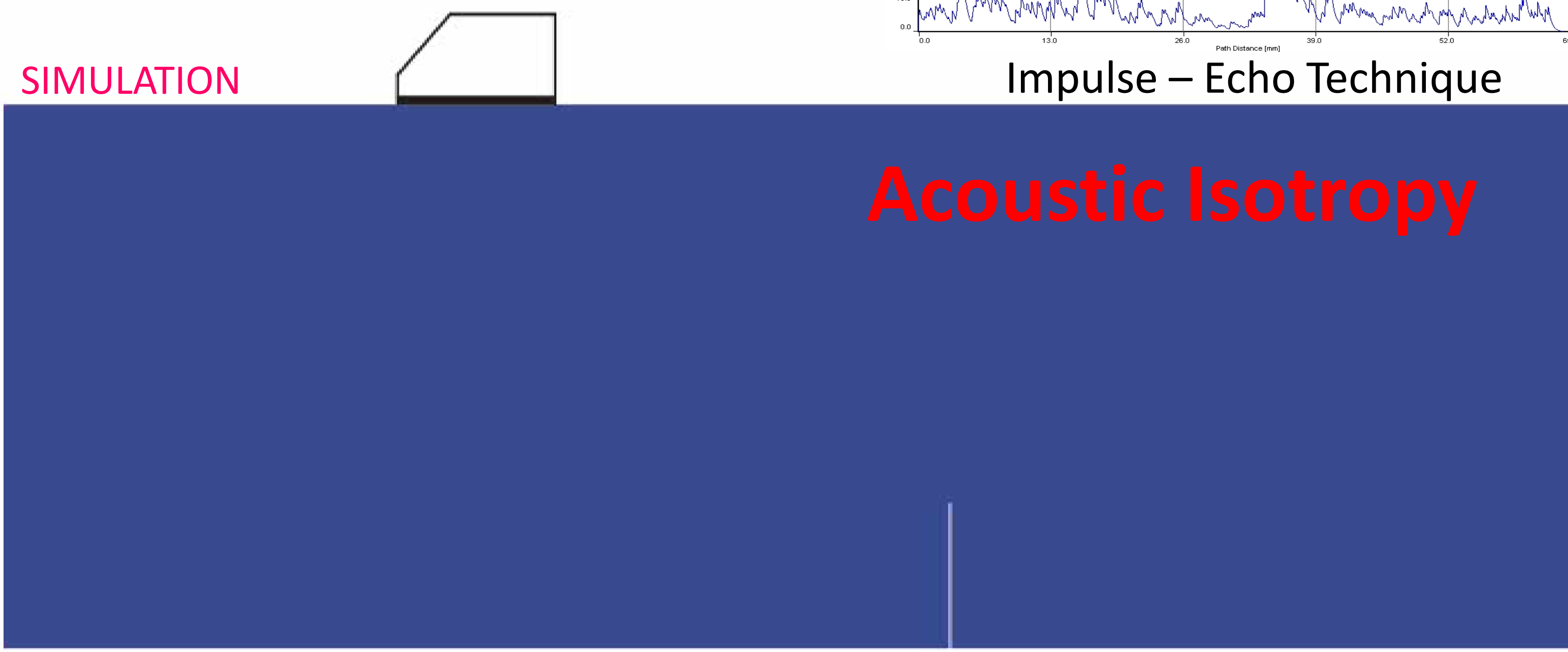
EXEMPLARY CASE: ULTRASONIC METHOD

CONTRAST of Impulse-Echo Technique:
Local Change of the Acoustic Impedance Z = pV
p: density; V: sound velocity

Reflection Coefficient R
$R = (Z_2 - Z_1) / (Z_2 + Z_1$



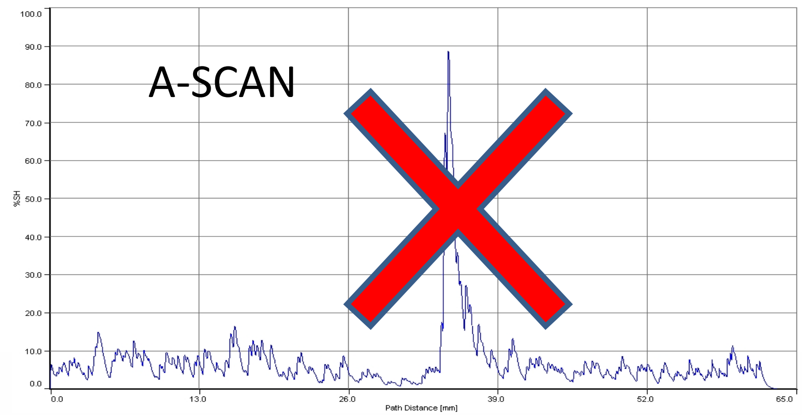
Impulse – Echo Technique



EXEMPLARY CASE: ULTRASONIC METHOD

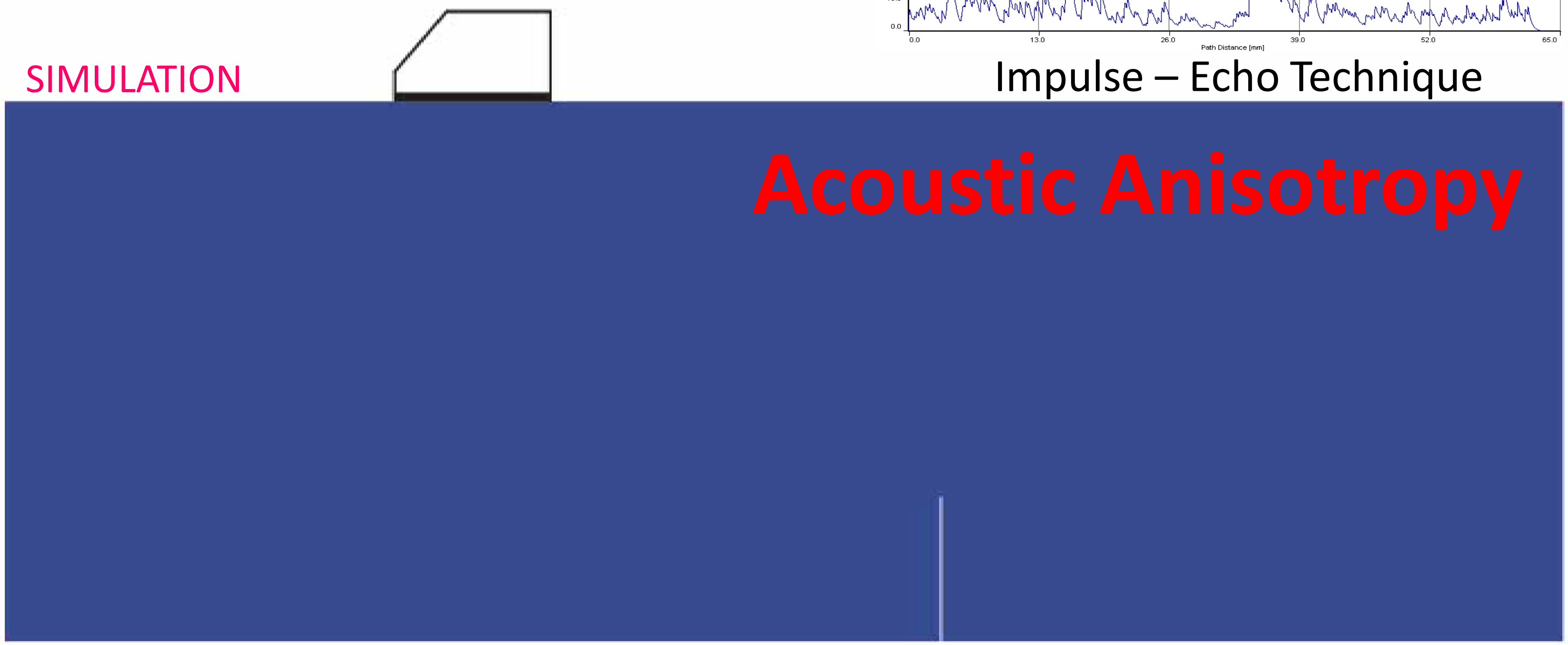
Assumption:

Straight-line pulse propagation

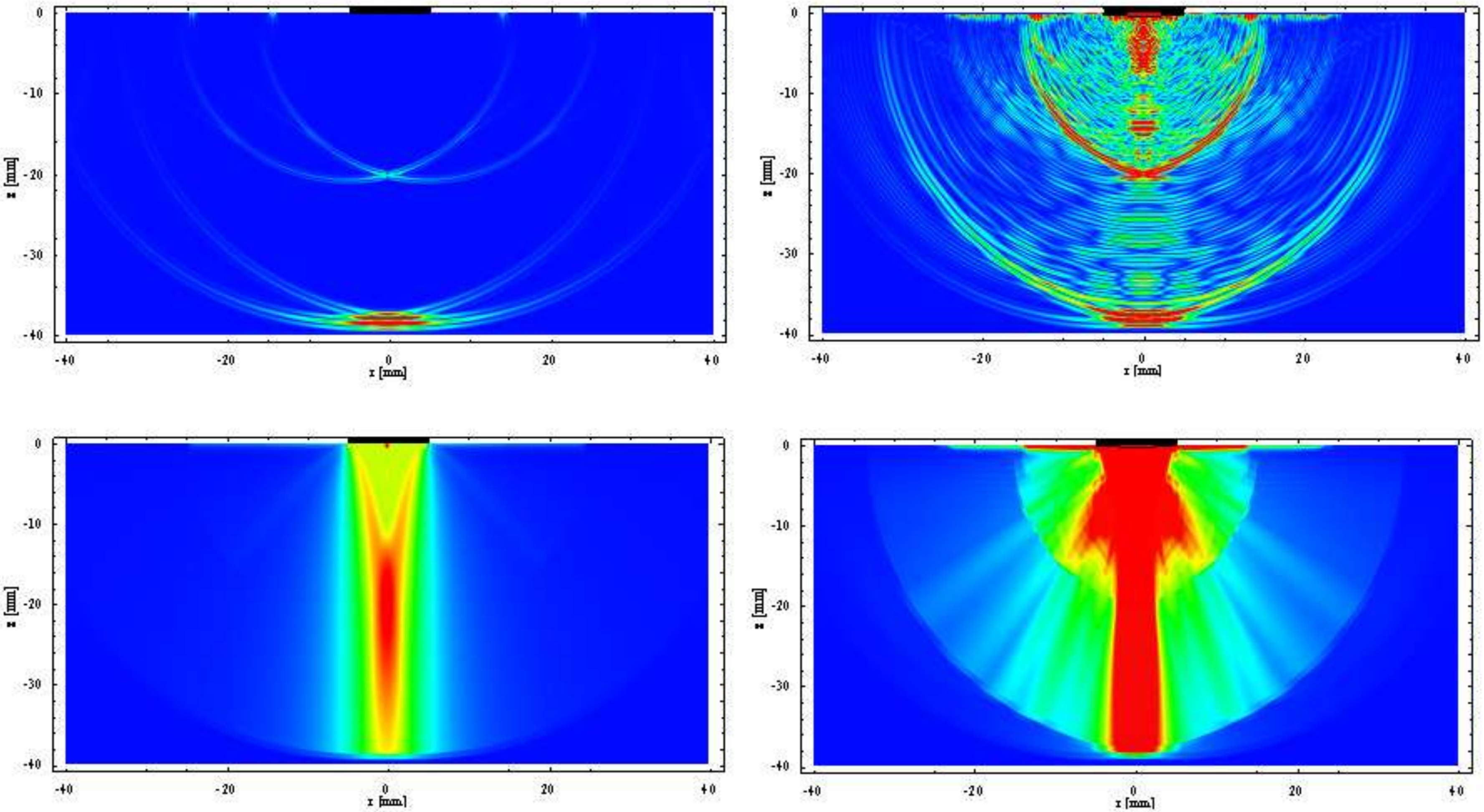


Impulse – Echo Technique

SIMULATION



ULTRASONIC TESTING
Coupling Requirements



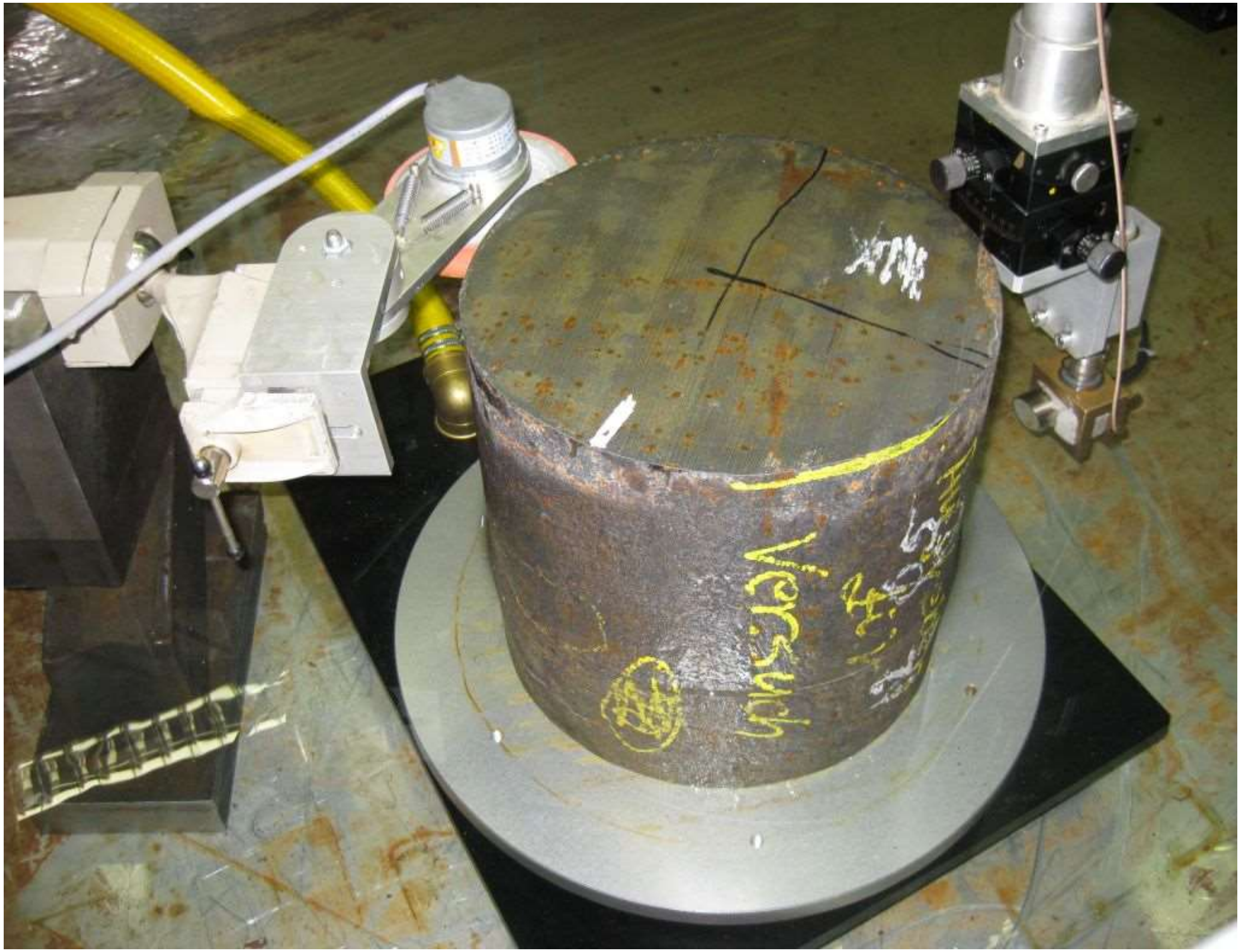
Frequency f = 4 MHz

Aperture A = 10 mm

Water gap depth (lense shaped):

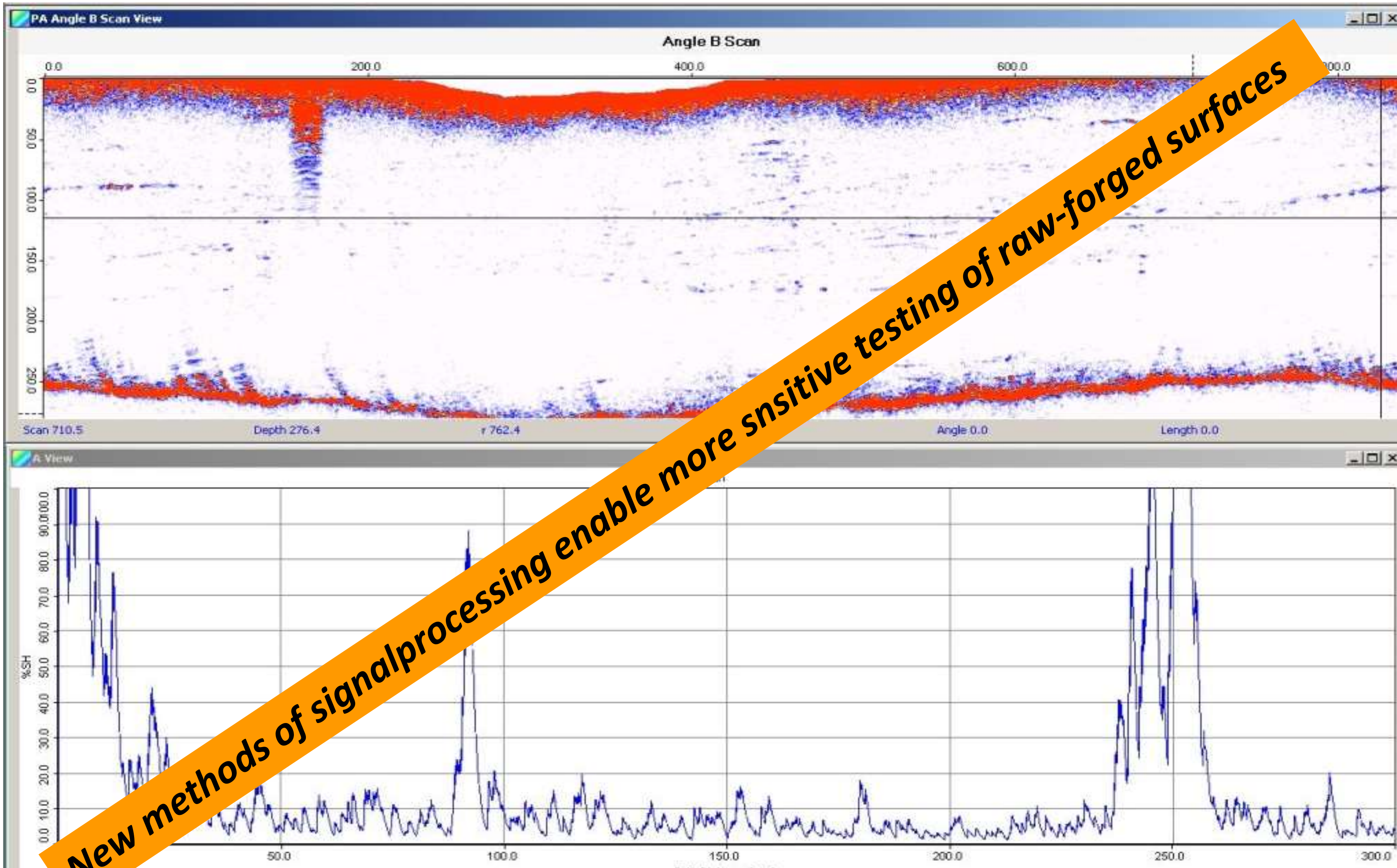
0.18 mm ($\lambda/8$ in steel, $\lambda/2$ in water)

Ultrasonic Inspection of Parts with Rough Surfaces



Specimen: Raw-forged steel bar with reference flaws

Ultrasonic Inspection of Parts with Rough Surfaces

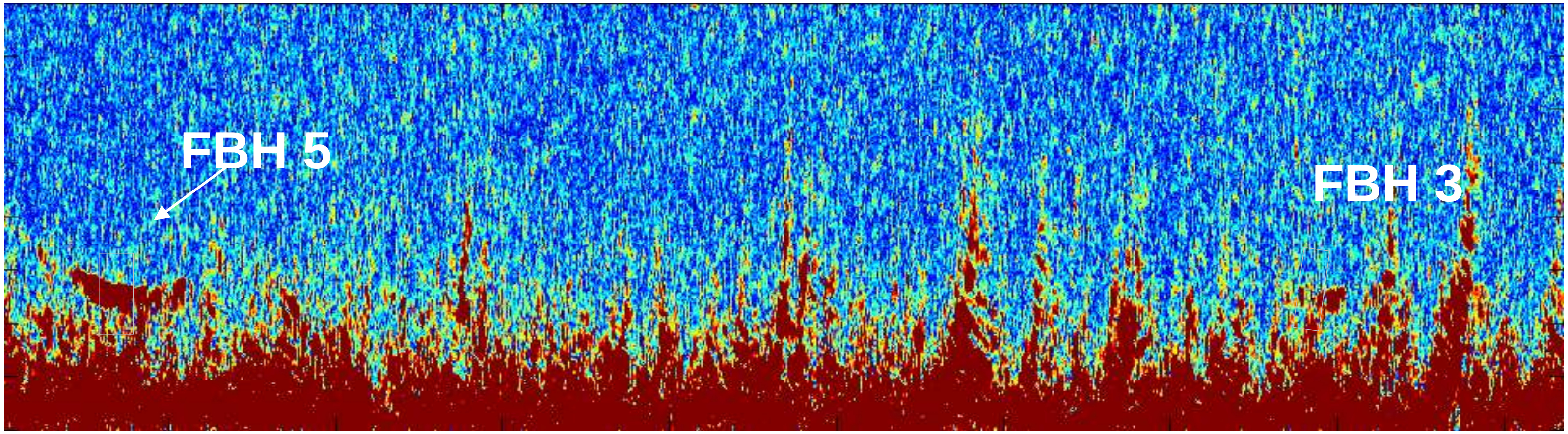


New methods of signalprocessing enable more snsitive testing of raw-forged surfaces

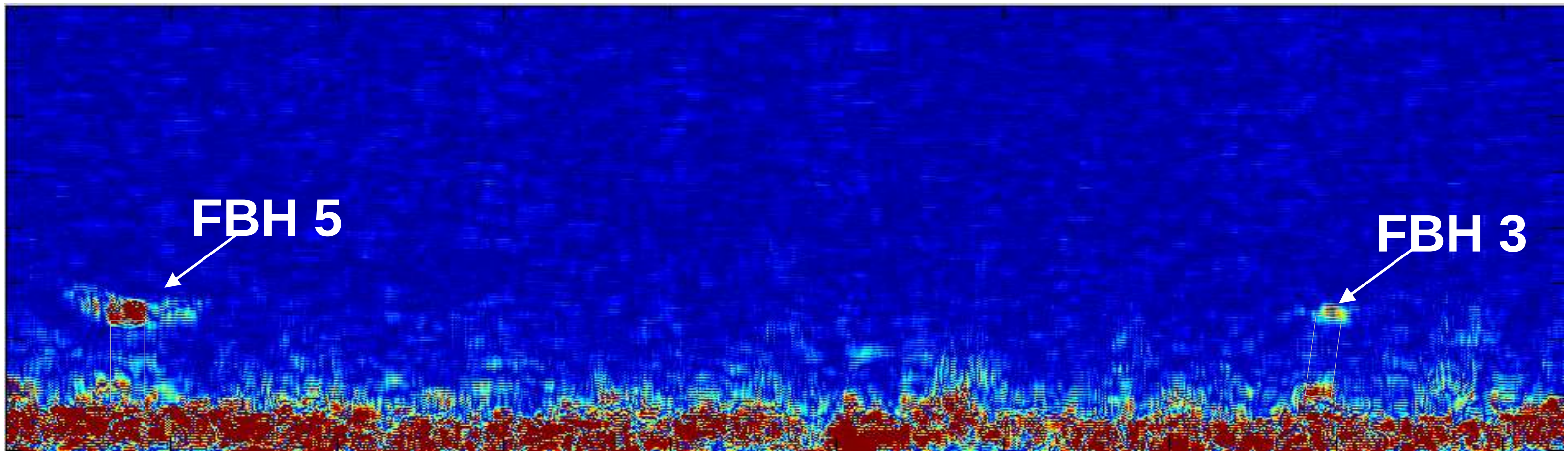
Ultrasonic Inspection of Parts with Rough Surfaces

Effect of Statistic Phase Filtering

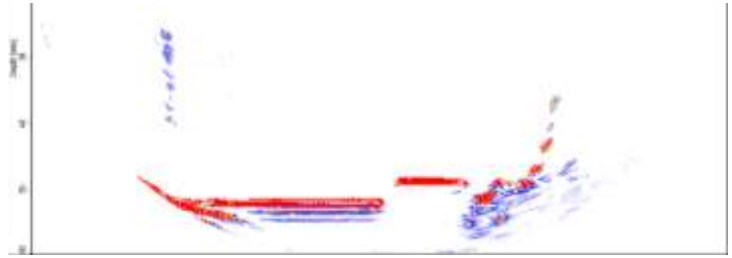
Virgin Image



De-noised Image



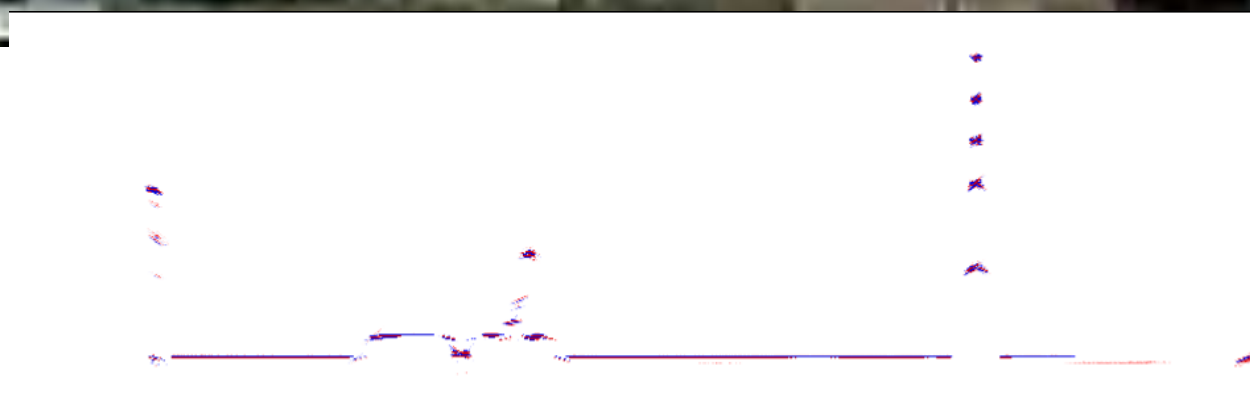
ULTRASONIC 2-D IMAGING



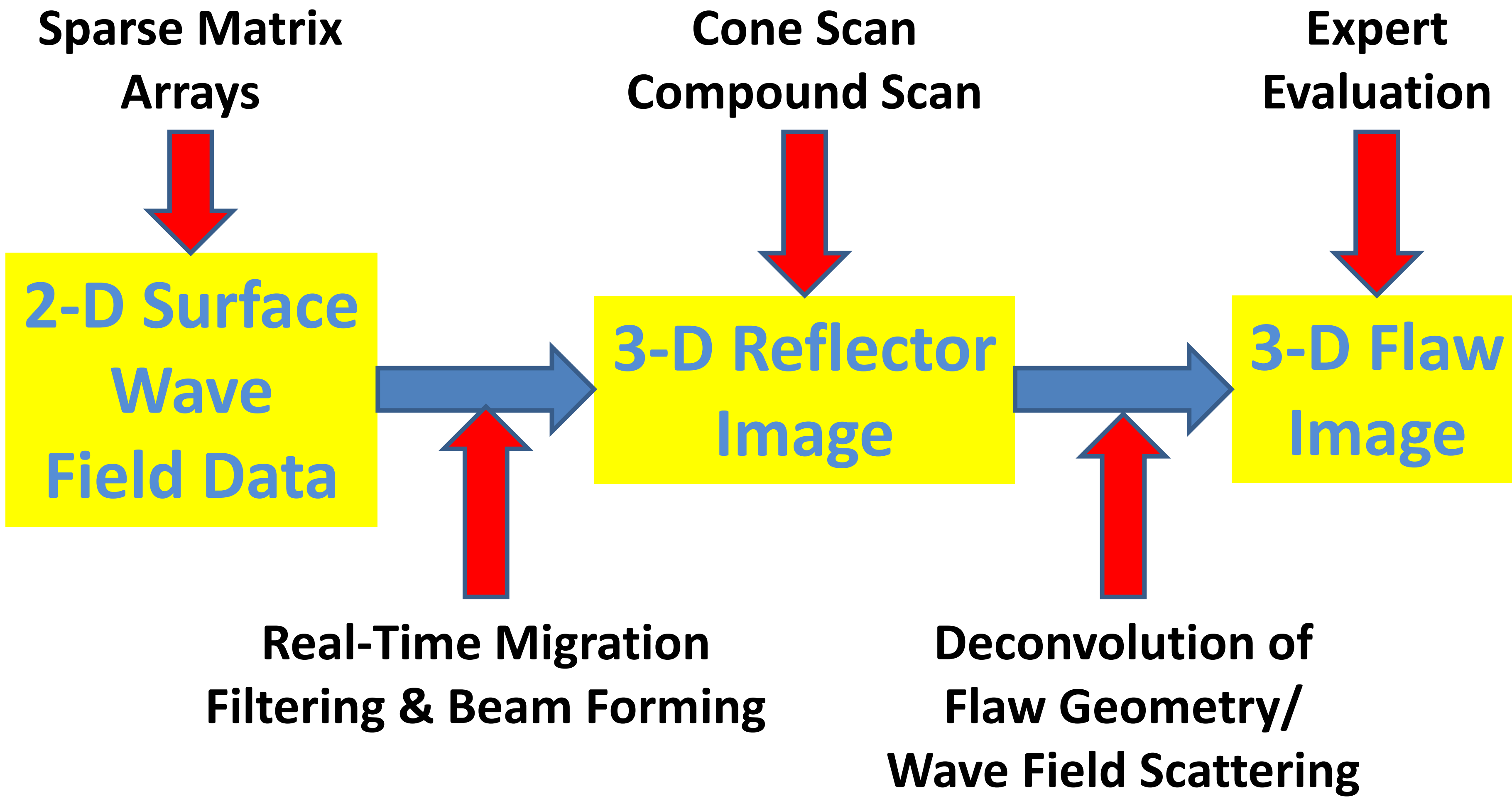
SECTORSCAN

ULTRASONIC 2-D IMAGING

2-D COMPOUND SCAN



R&D OBJECTIVES



Advanced UT Systems

CHALLENGE

Contradicting Requirements

High Contrast Sensitivity

High Resolution Sensitivity

Space Coverage

Large Beam Spread

Resolution in Space

3-D Imaging

DEFECT STATE

3-D Focusing

(Quantitative)

ULTRASONIC TESTING

Advanced UT Systems

Literature

1. Jacobi Consultant Limited: *Probability of Detection (PoD) Curves, Derivation, Applications and Limitations*, prepared for the Health and Safety Executive, 2006