MAPOD meeting
ASNT fall conference

Palm Springs, Nicolas Dominguez
27 October 2011

Overview

- **PICASSO project, progress**
- **IIW activity in relation with simulation and POD**

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PICASSO

Improved Reliablity Inspection of Aeronautic Structure through Simulation Supported POD

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imProved reliabIlity inspeCtion of Aeronautic structure through Simulation Supported POD

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14 partners

PICASSO
Improved Reliablity Inspection of Aeronautic Structure through Simulation Supported POD
Research
Fraunhofer
IZFP
CHALMERS
TWI
World Centre for Materials Joining Technology
SCeNDT
BAM
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SME
HTS
Hoch Technologie Systeme
TECHNIC-CONTROL
Spółka z o.o.
Rok założenia 1989
PHIMECA
Industry
Turbomeca
SAFRAN Group
ROLLS ROYCE
MTU
Aero Engines
EADS
Snecma
Groupe SAFRAN
VOLVO AERO

Why PICASSO?

- **In the context of aging engines/airframes and increase of air traffic in next 20 years, it is crucial to have a reliable predictive maintenance to**

Minimize unscheduled maintenance operations on engines and airframes which are cost and time consuming

Increase accuracy of damage tolerance analysis and consequently the level of safety

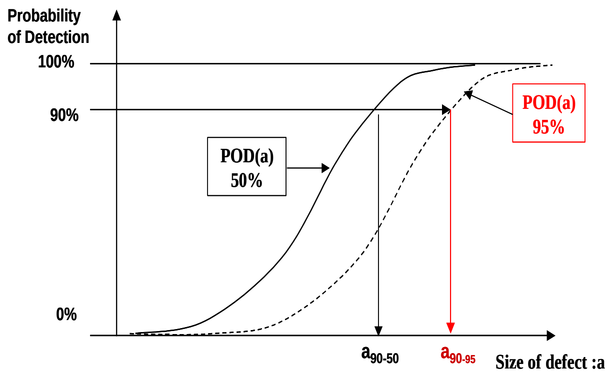
Main impacts of the project :

Improve the answer to FAA/EASA damage tolerance requirement with higher knowledge and accuracy on NDT inspection PODs

Savings in costs concerning aircraft maintenance and engine development *(avoidance of the manufacturing of expensive samples with defects)*

PICASSO
Improved Reliability Inspection of Aeronautic Structure through Simulation Supported POD

Objectives 1/2



Complete experimental NDT inspections by simulated NDT inspections

More representative samples population for POD campaign – enhancing the accuracy of the POD samples and increasing their numbers thanks to simulation techniques

Delta POD approach – limiting the need of a new POD campaign for similar part or inspection configurations

Increase the accuracy and overcome cost issue of a Probability of Detection campaign with Non Destructive Testing simulation

PICASSO
Improved Reliability Inspection of Aeronautic Structure through Simulation Supported POD

Objectives 2/2

	Experimental POD	Simulation supported POD
Sample manufacturing	• Difficult and expensive to manufacture real defects • Limited number of samples • Limited number of defects	• Simulation of complex defect geometries • Easy change of defect position • Large number of samples • Large number of defects
NDT campaign	• Several operators needed • Representativity of testing conditions difficult to manage (expensive)	• NDT procedure application • Help finding transfer from artificial to real defects responses • Human factor (cognitive) not treated in this framework
POD data management	• Fastidious data collection ((outliers)	• Automated data extraction and analysis • Data and uncertainty management
New POD configuration	• Need to redo everything (samples, defects, testing)	• Re-use proven input uncertainties for cousin configurations • Use transfer function to minimize new defects and testing

cea list

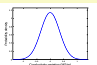
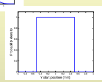
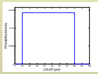
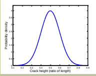
POD with simulation

Uncertainty propagation approach

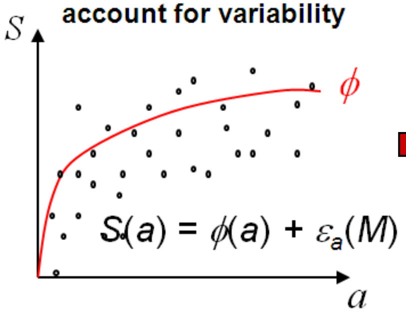
1. Definition of the inspection setup using the CIVA graphical user interface
2. Description of uncertainties on a set of input parameters
3. Propagation of uncertainty and noise computation using CIVA models
4. Estimation of statistics such as the POD, PFA, ROC…

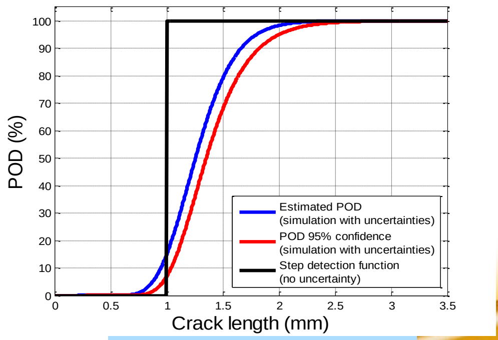
Input parameters — $\overline{X}$ → CIVA NDE 10 → $\overline{Y}$ — **Output Values**

With uncertainty — **Uncertainty propagation** → **With variability**

Input parameters:
- <u>Part</u>
  - Dimensions
  - Conductivity 
- <u>Inspection</u>
  - Start scan position 
  - Scan increment
  - Lift-off 
- <u>Flaw</u>
  - Shape
  - Length
  - Height 
  - Width

Targeted simulation: account for variability





POD, PFA, ROC

FIRST VALIDATION CASES

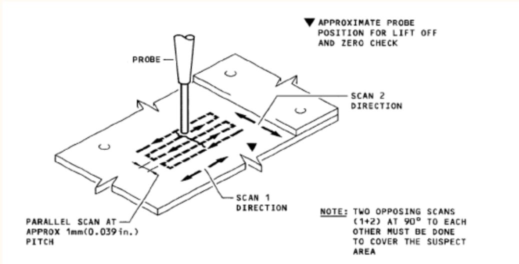
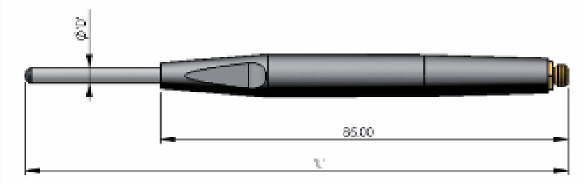
- **High Frequency Eddy Current Testing of fatigue cracks (in-service) in Titanium**

- **Phased Array Ultrasonic Testing in manufacturing**

FIRST VALIDATION CASES

- **High Frequency Eddy Current Testing of fatigue cracks (in-service) in Titanium**
- **Phased Array Ultrasonic Testing in manufacturing**

HFET of fatigue cracks in Titanium

Part	NDT
Material: Titanium (TA6V) **Geometry:** Flat areas **Defects:** Fatigue cracks	**Configuration:** High Frequency Eddy Currents Testing (HFET)  **Probe:** Pencil probe (2MHz)  **Conditions:** In-service (manual)

Design of Numerical Experiments

© EADS

- **Statistical description of input parameters**

Description of variables of the table :

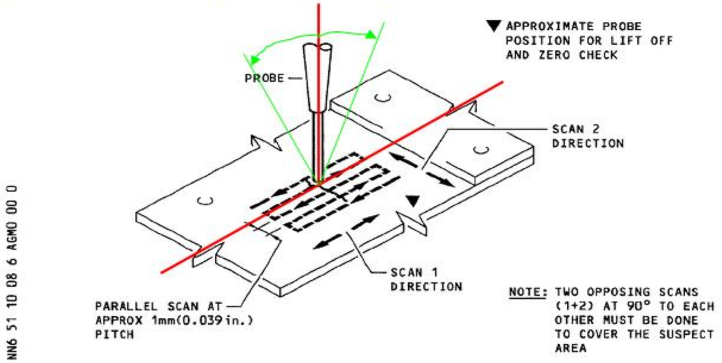
- **Lift-off (mm):**

Distance between the probe and the part, including:

- packaging of the probe
- Teflon thickness
- Any other possible source of lift-off

- **Angular position of the probe (orthogonal) (°):**

It is the normalitty error of the probe with respect to the part surface, in the plane orthogonal to the crack (scan direction assumed):.



Typical Procedure to Scan Open Surface Areas away from Fasteners or Section Changes
Figure 604

- **Angular position of the probe (parallel) (°):**

It is the normalitty error of the probe with respect to the part surface, in the plane of the crack:

Design of Numerical Experiments

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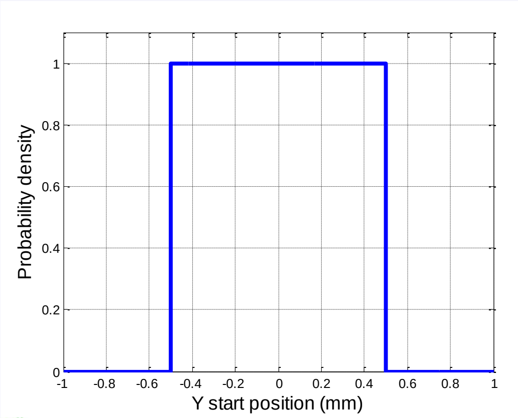
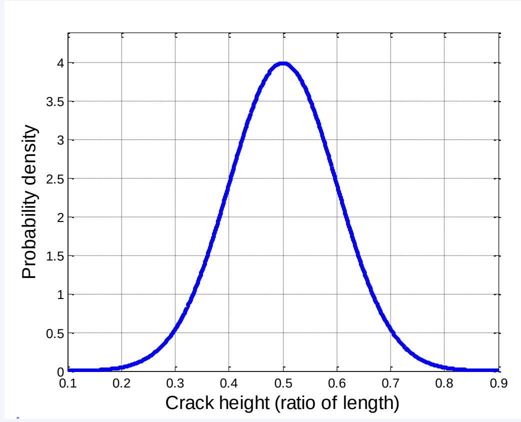
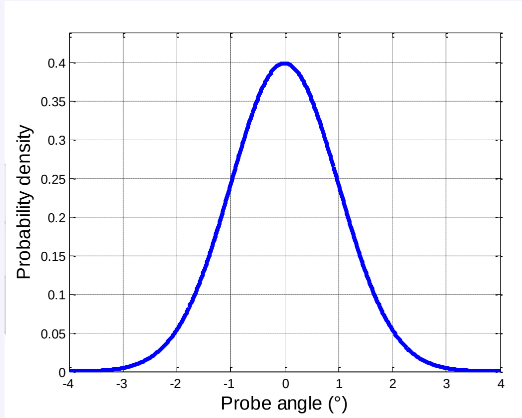
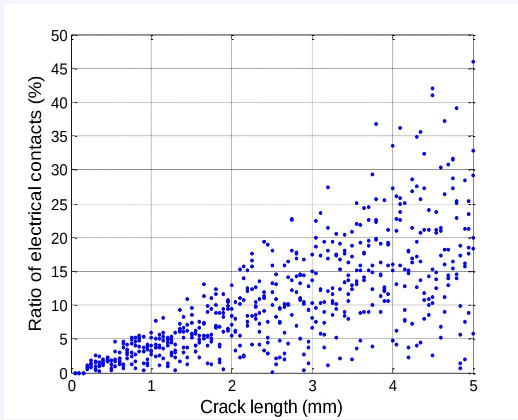
- <u>Characteristic variable</u>: crack length (mm)
- <u>Uncertain parameters description</u>:

Start scan position	Crack height (mm)	Angle of the probe (°)	Crack electrical contacts
Corresponds to the position of the probe for picking the max amplitude signal	Fatigue cracking is subject to many uncertainties	Translated into an additional lift-off using geometrical rule	
			
Uniform in [-0.5;05] (scan increment=1mm)	Gaussian with dependency to the crack length (fatigue crack) 0.5*length +$\mathcal{N}$(0,1)*0.12*length	Gaussian(0°;1°)	

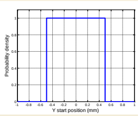
Sampling strategy: Monte Carlo

Uncertainty propagation thru CIVA

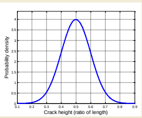
Procedure settings (phase rotation) and calibration (gain setting) are applied by automatic data extraction

Input parameters:

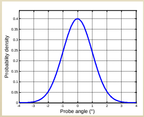
- **Part**
  - Dimensions
  - Conductivity...
- **Probe**
  - Dimensions
  - Number of turns
  - Frequency
- **Inspection**
  - Start scan position



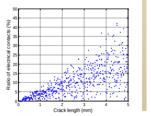
  - Scan increment
  - Probe angle



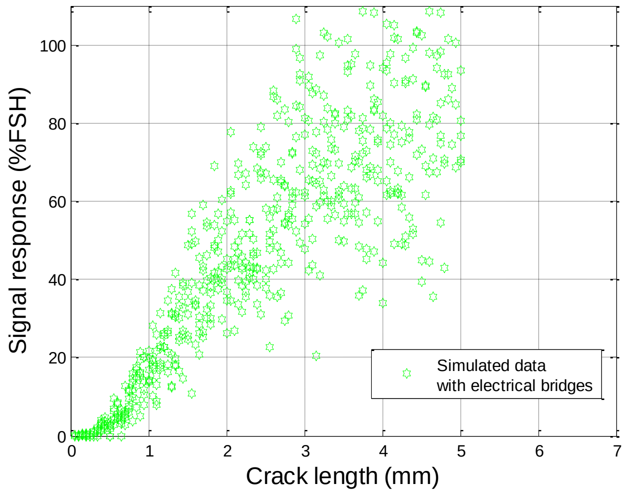
- **Flaw**
  - Shape
  - Length

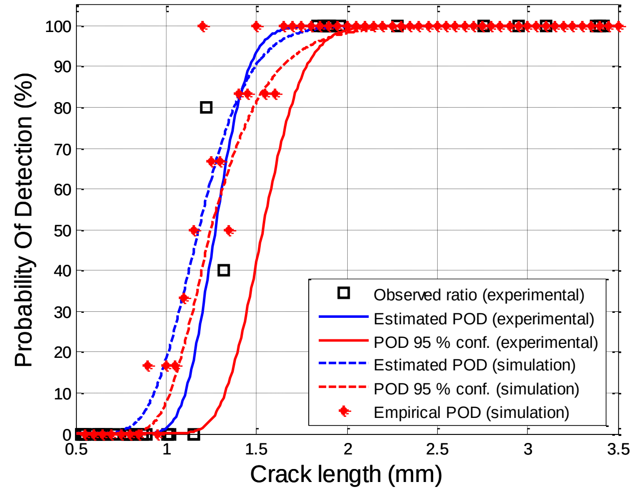


  - Height
  - Width
  - Electrical contacts



CIVA NDE 10





HFET fatigue cracks in Ti: POD results

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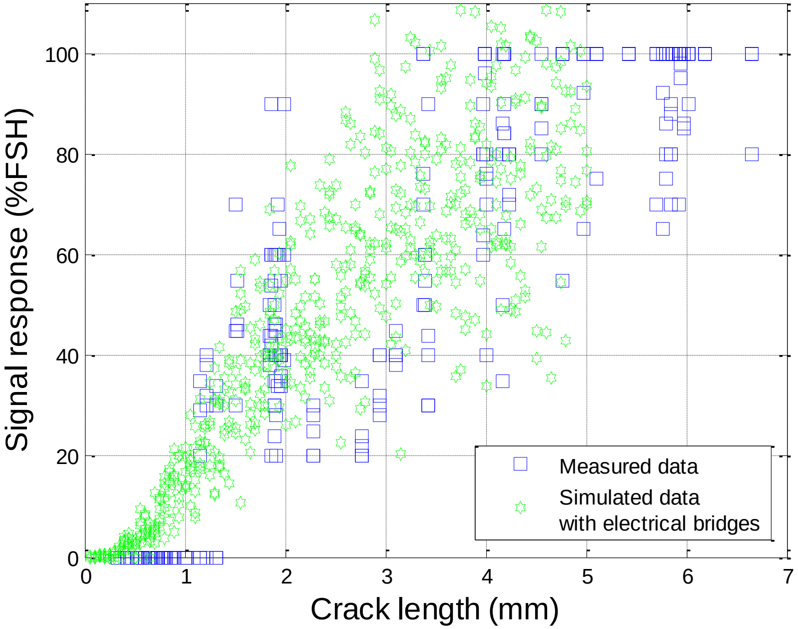
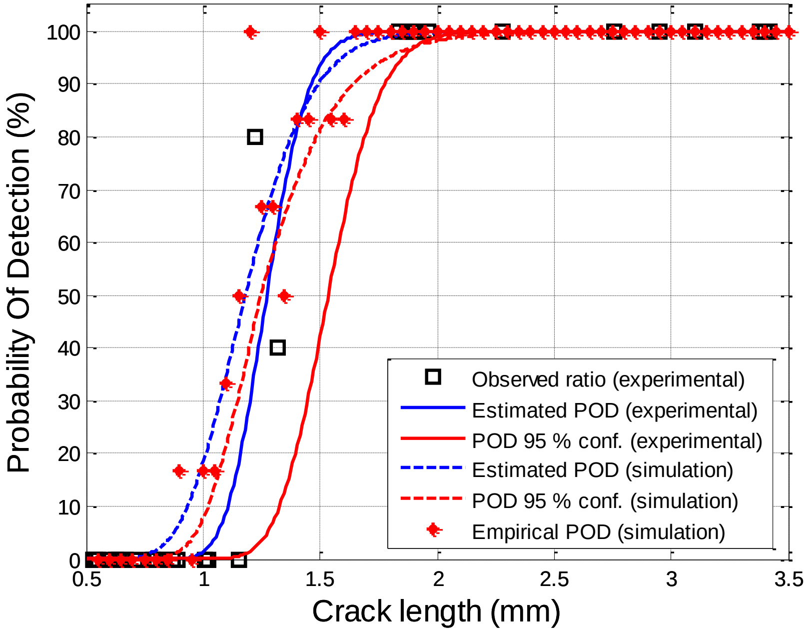
- **Experimental data: 69 cracks and 5 operators**
- **Simulation data: 600 simulated data**





POD curves very similar

Conf. band smaller for simulation because more data than in the experimental dataset

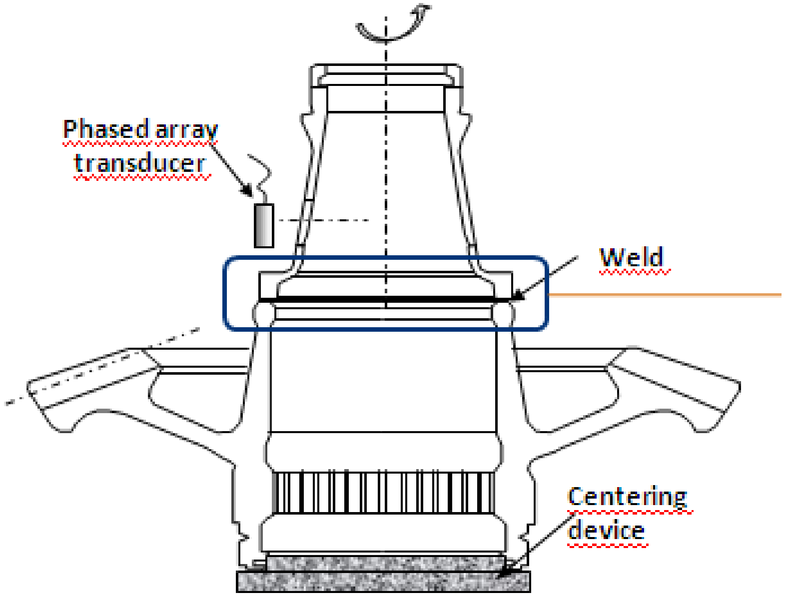
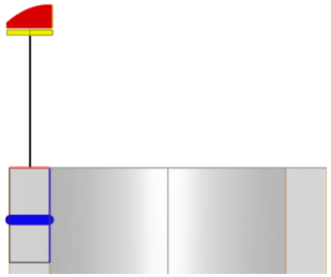
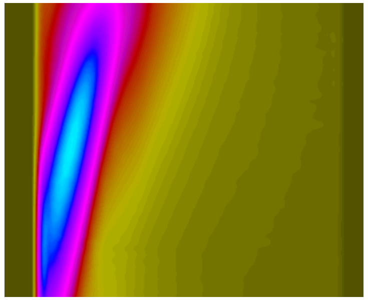
$$\begin{cases} a_{90}^{\exp} = 1.5mm \\ a_{90/95}^{\exp} = 1.8mm \end{cases} \qquad \begin{cases} a_{90}^{simu,EC} = 1.5mm \\ a_{90/95}^{simu,EC} = 1.7mm \end{cases}$$

Values of interest very similar

FIRST VALIDATION CASES

- **High Frequency Eddy Current Testing of fatigue cracks (in-service) in Titanium**
- **Phased Array Ultrasonic Testing in manufacturing**

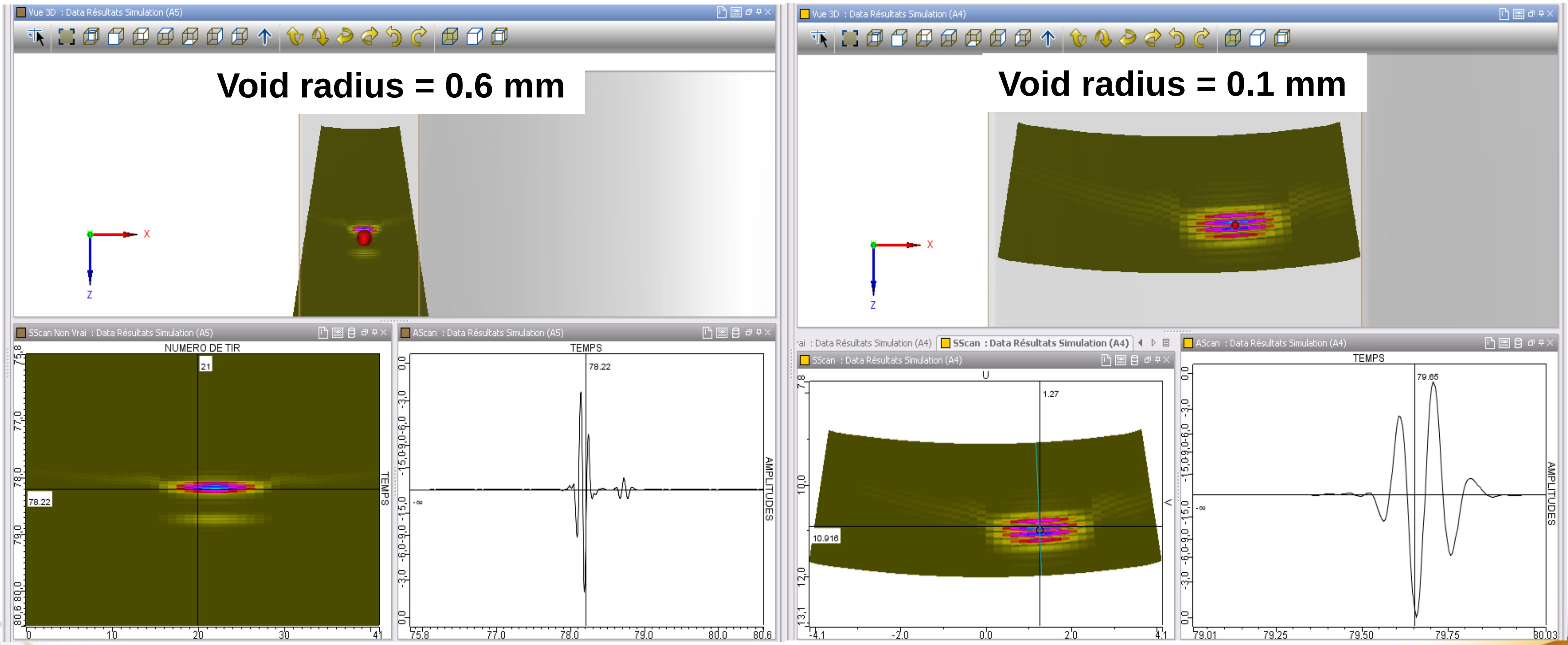
Phase Array UT of Electron Beam Welds in manufacturing

Part	NDT
 **Material:** Steel **Electron Beam Welding** **Geometry:** Locally flat areas **Defects:** Voids	**Configuration:** Phased array UT Multi-points focusing along the weld (0.2 mm pitch) 0.2 mm increment on external radius   **Probe:** Linear array 32 elements, pitch 0.3 mm, 10 MHz central frequency **Conditions:** In-plant (automated rotation)

Choice of UT defect response model

- **SOV model for small voids (ka<1)**

SOV: Separation Of Variables (Ying & Truell)
(exact formulation for spheres and cylinders)

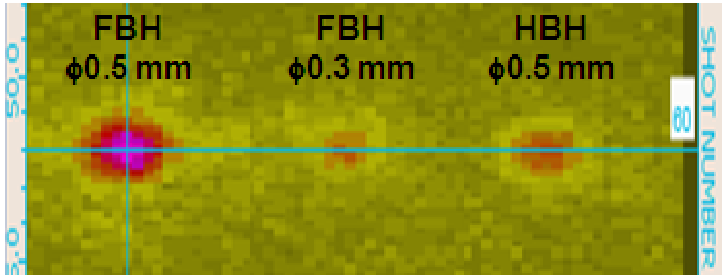


Choice of UT defect response model

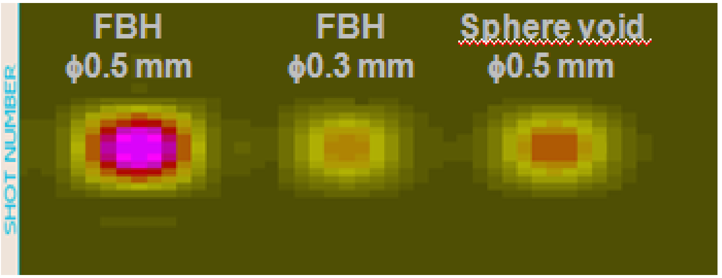
- **Comparison with experiments / calibration**

Spherical voids are replaced by Hemispherical Bottom Holes (HBH) in the reference block

Experimental result



Simulation result
(without material noise)



1.5 dB deviation « Simulation-SOV / Experiment-HBH » after calibration on FBH 0.5 mm

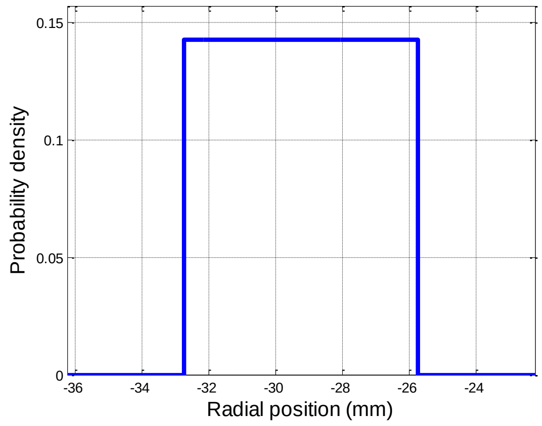
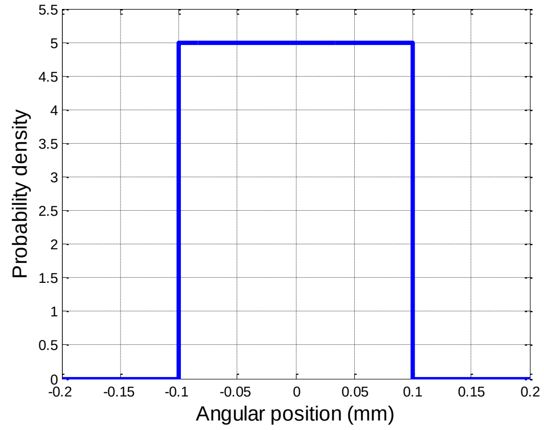
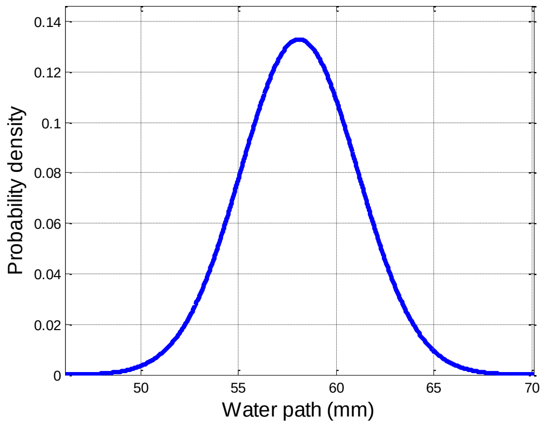
Repeatability measurements showed that experimental results on HBH vary within 1.0 dB

➡ **Very acceptable results (sphere≠HBH)**

Design of Numerical Experiments

- **Characteristic variable: void radius (mm)**
- **Uncertain parameters description:**

Good characterization of uncertainties is much easier for automated NDT

Defect radial position	Defect angular position (mm)	Water path (mm)
Position of the defect along the radial axis	Position of the defect in the angular direction (relative to the probe)	
		
Uniform along the weld	Uniform [-0.1;0.1] mm on external radius	Gaussian with 3mm standard deviation

Sampling strategy: Monte Carlo

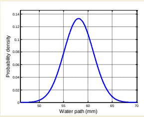
Uncertainty propagation thru CIVA

© EADS

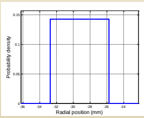
Procedure settings and calibration are applied by automatic data extraction

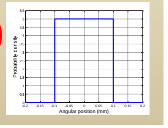
Input parameters:

- **<u>Part</u>**
  - Dimensions
  - Steel properties...
- **<u>Probe</u>**
  - Geometry
  - Frequency
  - Phased array settings
- **<u>Inspection</u>**
  - Water path
  - Scan type
  - Scan increment

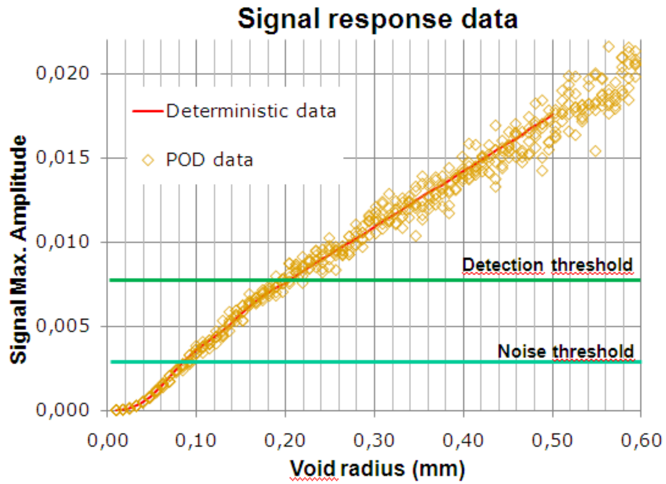


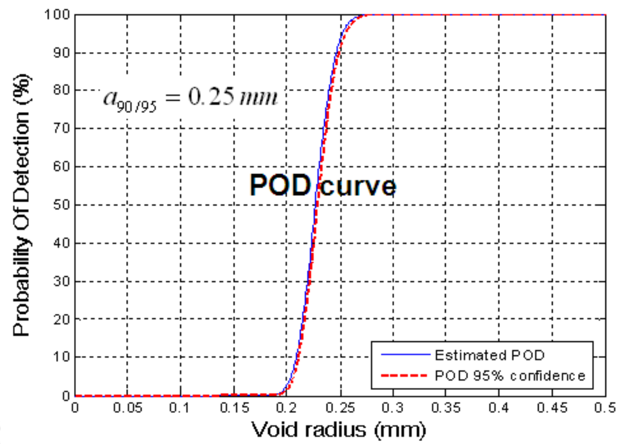
- **<u>Flaw</u>**
  - Type (void)
  - Position (radial)
  - Position (angular)





CIVA NDE 10



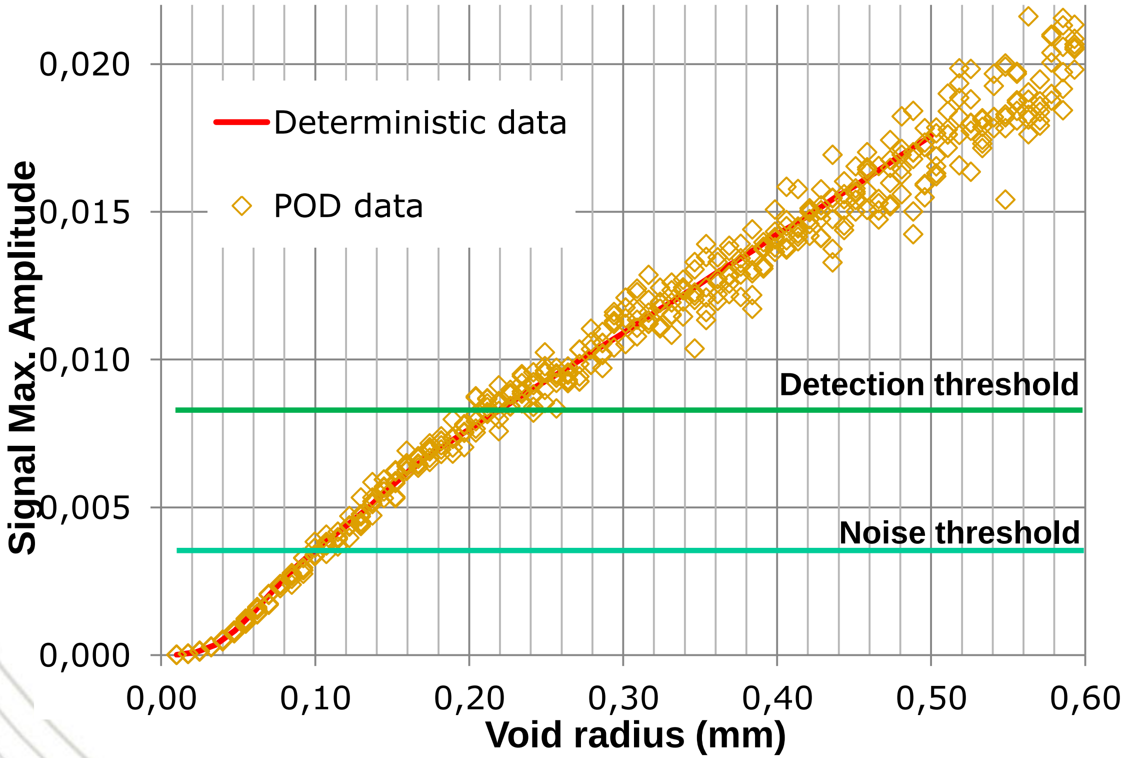


PAUT of Electron Beam Welds: POD results

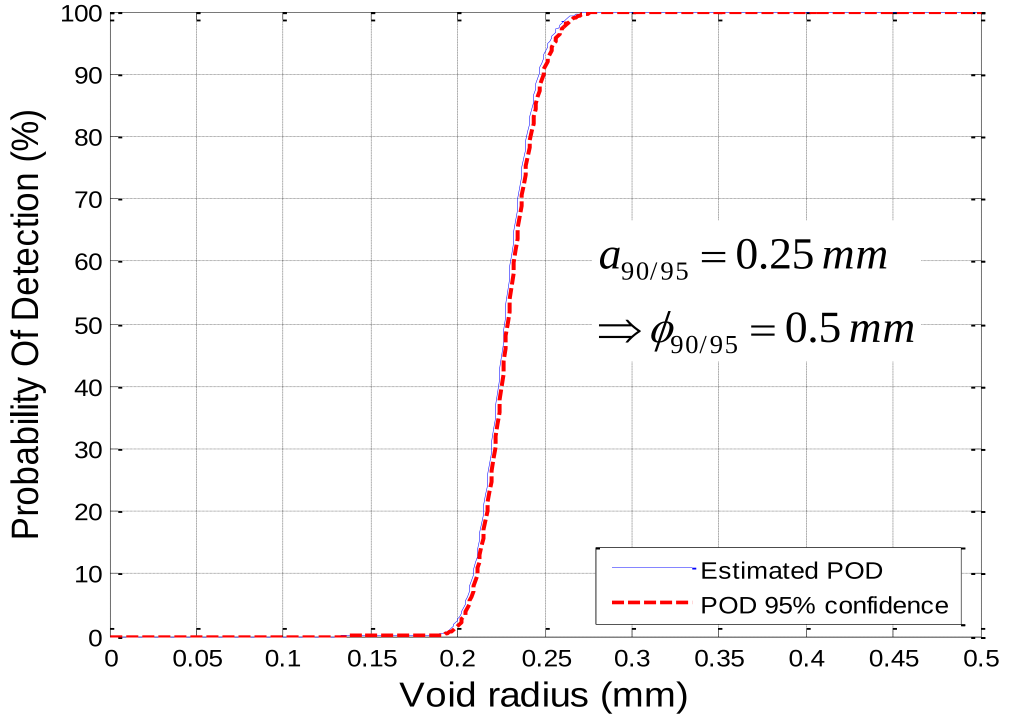
- **Design of numerical experiments**
  - **100 voids, radii from 0.01 mm to 0.75 mm**
  - **6 samples per void radius**

  ⇒ 600 simulations in total

Signal response data



POD curve



No full experimental POD exist for this particular NDT case
The procedure was set-up to detect voids of ϕ 0.5 mm
(experimental evidence)

Simulation-based transfer function attempt

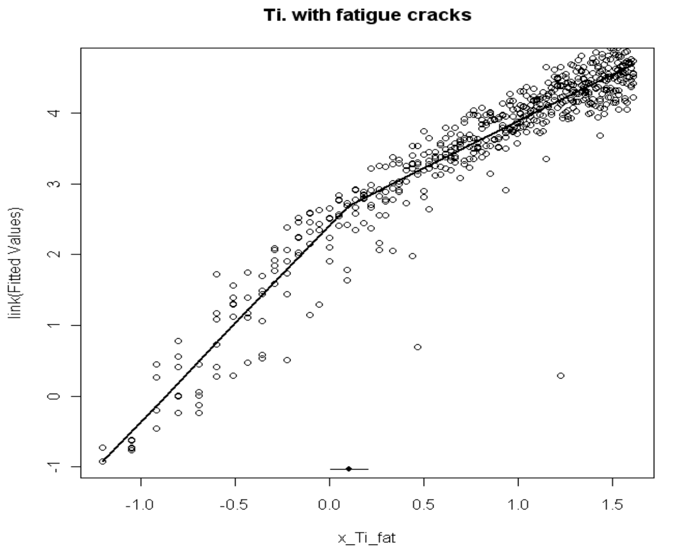
- **S. Demeyer et al. QNDE 2011**
  - Application of Harding & Hugo methodology for a use with simulation

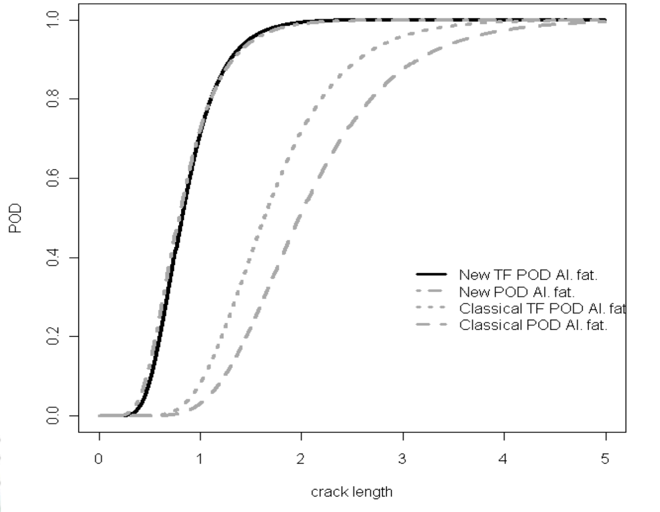
$$\frac{y_i^{exp,Ti}}{y_i^{sim,Ti}} = \frac{y_i^{trans,Al}}{y_i^{sim,Al}},\ i = 1 \ldots n \Rightarrow \begin{cases} \beta_0^{trans,Al} = \beta_0^{\exp,Ti} + \beta_0^{sim,Al} - \beta_0^{sim,Ti} \\ \beta_1^{trans,Al} = \beta_1^{\exp,Ti} + \beta_1^{sim,Al} - \beta_1^{sim,Ti} \\ \delta^{trans,Al\,2} = \delta^{\exp,Ti\,2} \end{cases} \Rightarrow \hat{y}_i^{trans,Al} = \beta_0^{trans,Al} + \beta_1^{trans,Al} x_i$$

  - Piecewize transfer function

$$\log(y_i) = \begin{cases} \beta_0 + \beta_1 \log(x_i) + \varepsilon_i \ \ if \ \ x_i \le \tau \\ \beta_0 + \beta_1 \log(x_i) + \beta_2(\log(x_i) - \tau) + \tilde{\varepsilon}_i \ if \ \ x_i > \tau \end{cases}$$

$$POD_{[k]}^{trans,Al}(x_i) = P\left(\tilde{y}_{i[k]}^{trans,Al} > y_{th} \middle| X = x_i\right) = \Phi\left(\frac{\log(x_i) - \mu_{[k]}}{\sigma_{[k]}}\right)$$





PICASSO

- **First conclusions**
  - The uncertainty propagation in CIVA has already been proven relevant in two configurations (ET and UT)
  - Implementation is much easier for automated NDT (uncertainty description in input)
  - Work has to be done to make more robust the approach in case of in-service (manual) inspections

- **Running in PICASSO**
  - Industrial partners are running test cases
  - Physical models are improved (when needed) to deal with test cases
  - Statistical library is being built including state of the art (MIL-HDBK 1823 MLE) and alternative estimation techniques
  - POD when results are images (RT, TOFD)

PICASSO interactions with MAPOD WG

Participation to MAPOD WG meetings

PICASSO — Improved Reliability Inspection of Aeronautic Structure through Simulation Supported POD — **at QNDE 2011, Burlington, VT**

4 presentations from PICASSO made within the POD session

- **Transfer function approach based on simulation for the determination of POD curves,**
  S. Demeyer, F. Jenson, N. Dominguez
- **Simulation-Assisted POD of a phased array UT in manufacturing,**
  N. Dominguez, F. Jenson, V. Feuillard and P. Willaume
- **POD generated by Monte-Carlo simulation using a meta-model on the simSUNDT software,**
  G. Persson, P. Hammersberg, H. Wirdelius
- **Simulation of Ultrasonic scattering from inclusions using Laser engravings in Glass samples,**
  J. Menges, J. Bamberg, H-U. Baron, F. Schubert

Further contacts and exchanges

Invitation of E. Lindgren and J. Aldrin to the next PICASSO review meeting December in Paris

Other connected business

- **International Institute of Welding (Frame)**

Document for

”RECOMMENDATIONS FOR THE USE AND VALIDATION OF NDT SIMULATION”

(V-1480 10)

IIW « Recommendations for the use and validation of NDT simulation »

- <u>Scope of the document</u>

Guidelines for

the use of simulation in NDT and for the validation of codes and models

⇒ **Propose "good practices" for NDT simulation use and validation**

⇒ **Promote a uniform approach for the validation of NDT simulation**

⇒ **Make possible the creation of a validation database**

- <u>Status of the document</u>
  - **Proposed in 2010 following decision taken at Berlin in 2009**
  - **Submitted to an international panel of experts (April 2011):** Bob Chapman (British Energy), Mark Dennis (EPRI), Gerard Cattiaux (IRSN), Evgueni Todorov (EWI), Ruediger Jaenisch (BAM), Nicolas Dominguez (EADS), Olivier Dupond (EDF), Erik Lindgren (USAF), Bernard Bisiaux (Vallourec).
  - **Integration of comments in the document**

IIW « Recommendations for the use and validation of NDT simulation »

Content:

1. INTRODUCTION
2. CONSIDERATIONS AND RECOMMENDATIONS ON THE USE OF NDT SIMULATION
3. CONSIDERATIONS AND RECOMMENDATIONS FOR THE VALIDATION OF CODES
4. RECOMMENDATIONS FOR INSCRIPTION IN VALIDATION DATA BASIS

IIW « Recommendations for the use and validation of NDT simulation »

2. CONSIDERATIONS AND RECOMMENDATIONS ON THE USE OF NDT SIMULATION

2.1 Scope and definitions

2.2 Typical ways of using simulation as element of technical justification

Flaw response computation
• Detection peformances
• Influence of essential parameters
• Determine « worst case »
• Interpolation between experiments
• POD study

Excitation field computation
• Sensitivity of a probe
• Understanding of energy distribution for defect response
• Influence of essential parameters

2.3 Main advantages of simulation

2.4 Different types of simulation tools

2.5 Considerations when using simulation

2.6 Recommendations when using simulation

IIW « Recommendations for the use and validation of NDT simulation »

2. CONSIDERATIONS AND RECOMMENDATIONS ON THE USE OF NDT SIMULATION

2.1 Scope and definitions

2.2 Typical ways of using simulation as element of technical justification

2.3 Main advantages of simulation ⇨ **Speed, cost, versatility, understanding …**

2.4 Different types of simulation tools ⇨
Function (predictive/partly predictive)
Model: analytical, semi-analytical, numerical, …
NDT-oriented / generalist code

2.5 Considerations when using simulation ⇨
Physical basis of the model,
Numerical performances/computer ressources,
Personnel competences …

2.6 Recommendations when using simulation

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3. CONSIDERATIONS AND RECOMMENDATIONS FOR THE VALIDATION OF CODES

3.1. Scope and definitions

3.2. Considerations on accuracy and uncertainties in the context of validation

3.2.1. Possible origins of discrepancy between experiment and simulation

1. Experimental variability (repeat & reproduce)
2. Determination of input parameters of simulations
3. Numerical uncertainties (i.e. mesh, computation parameters)
4. Model approximations
5. Bugs in implementation

3.3. Considerations on "numerical" validations

3.4. Recommendations for the realization of experimental validations

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3. CONSIDERATIONS AND RECOMMENDATIONS FOR THE VALIDATION OF CODES

3.1. Scope and definitions

3.2. Considerations on accuracy and uncertainties in the context of validation

3.2.1. Possible origins of discrepancy between experiment and simulation

3.2.2. Scope of the validation

Ex. 3: to evaluate the validity of the theoretical model (or a part of the model)

3.3. Considerations on "numerical" validations

3.4. Recommendations for the realization of experimental validations

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3. CONSIDERATIONS AND RECOMMENDATIONS FOR THE VALIDATION OF CODES

3.1. Scope and definitions

3.2. Considerations on accuracy and uncertainties in the context of validation

3.2.1. Possible origins of discrepancy between experiment and simulation

3.2.2. Scope of the validation

3.2.3. Experimental variability (repeatability – reproducibility)

3.2.4. Uncertainty linked to the determination of the inputs of the simulation

3.2.5. Numerical uncertainties

3.2.6. Software test (out of document scope)

3.3. Considerations on “numerical” validations

3.4. Recommendations for the realization of experimental validations

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3. CONSIDERATIONS AND RECOMMENDATIONS FOR THE VALIDATION OF CODES

3.1. Scope and definitions

3.2. Considerations on accuracy and uncertainties in the context of validation

3.3. Considerations on "numerical" validations

3.4. Recommendations for the realization of experimental validations

The goal is to

- **identify and quantify the part of the discrepancy which is due to the simulation**
- **Provide indicators to help decision making on validation (also the range of validity)**

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4. RECOMMENDATIONS FOR INSCRIPTION IN VALIDATION DATA BASIS

4.1. Inscription of experimental data in a validation database

To make possible future use by the NDT community of the data

Information must be as clear and detailed as possible (within limits imposed by confidentiality considerations)

Useful data are listed in the document (experimental set up, material characteristics, report of measurements, experimental accuracy, etc...)

4.2. Inscription of comparison results in a validation database

Validation data (report of a sim/exp comparison for a code or model) will be helpful if accompanied by a comprehensive description of both experiment and simulation

IIW « Recommendations for the use and validation of NDT simulation »

- **Corrections/comments/contributions are welcome!**
- **Topics to be discussed:**

  - Type of data ready to be exchanged
  - Availability of these data
  - Way to exchange
  - Necessity to produce, analyze the (shared) data
  - Availability of mockups (and mockups data i.e. welds definitions)
  - Published data: is information detailed enough ?