

CIVA : MODELLING FOR NDT

-

Fabrice FOUCHER (Extende)

NDT KONFERANSEN 2024

Radisson Blu Hotel Bodø, 9.-11. juni 2024



EXTEN·D·E
CIVA

Outline

- | Introduction
- | About CIVA simulation platform
- | Benefits of simulation tools and applications
- | Conclusion

About EXTENDE : Our activities

World wide CIVA DISTRIBUTION
and technical SUPPORT



TRAINING COURSES :
CIVA, « Reliability in NDE »

CONSULTING : qualifications,
design, expert assessment,
computations, ...



TraiNDE : Virtual training tool
for NDE operators



10487010



NDT KONFERANSEN 2024

Radisson Blu Hotel Bodø, 9.-11. juni 2024

page 3



CIVA in a few words

| Software platform **dedicated** to **NDE & SHM** simulation & analysis

| Multi-technique **Simulation**:



UT: Ultrasounds



RT-CT: Radiography (Gamma and X Rays) & Computed Tomography



ET: Eddy Current



GWT: Guided Waves



SHM-GWT: Structural Health Monitoring by Guided Waves



TT : Thermography Testing



AUT Pipeline simulation

| Data **Analysis**  , Data **Sciences** 
and **scripting** capacities 



| Two versions :

- CIVA « Experts »
- CIVA Education (UT, ET, RT)

| Developed by R&D Center :

CEA LIST



| Exclusive Distribution :



NDT KONFERANSEN 2024

Radisson Blu Hotel Bodø, 9-11. juni 2024





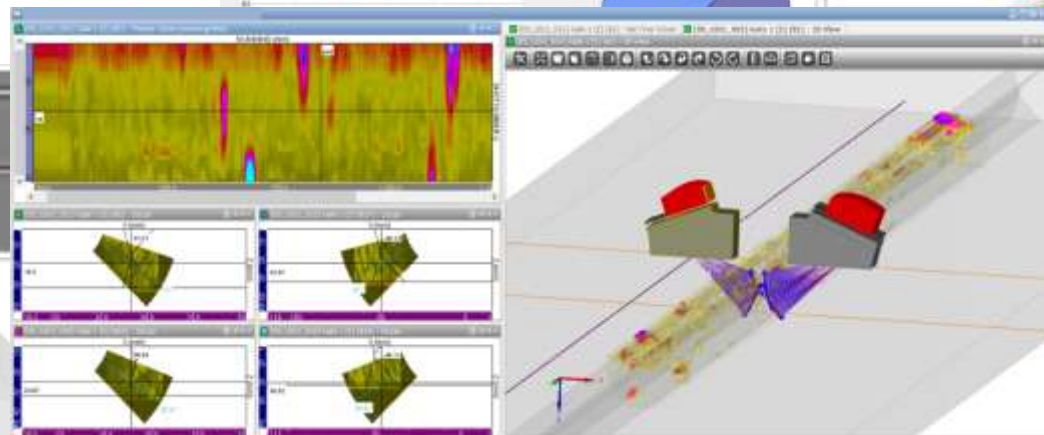
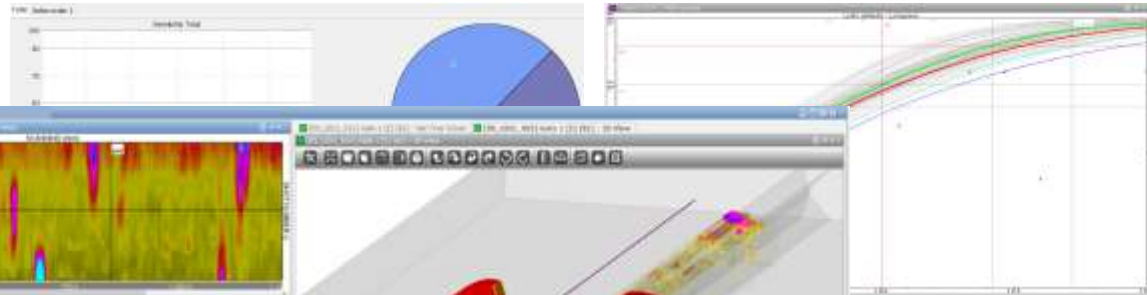
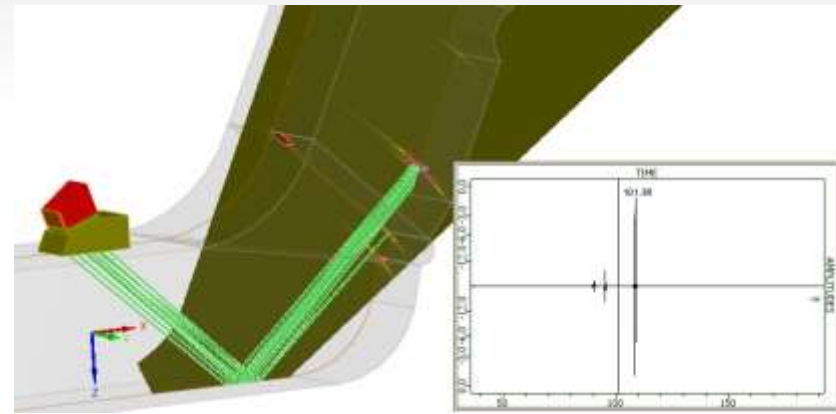
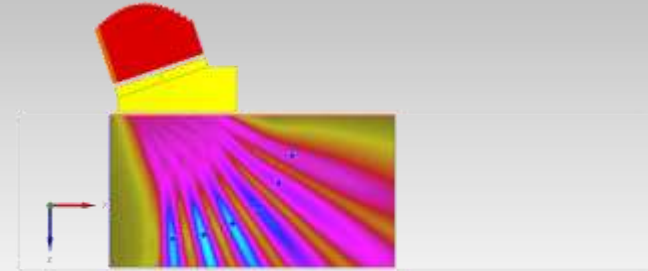
CIVA UT

CIVA UT includes:

- Beam Calculation tool
- PA settings calculations (delay laws, etc.)
- Inspection Simulation tool (predict echoes)
- Sensitivity analysis & POD curves computation
- UT data analysis

Techniques covered:

- Pulse-echo conventional UT
- Phased-Array: S-Scan, E-Scan, TFM, etc.
- Tandem
- TOFD





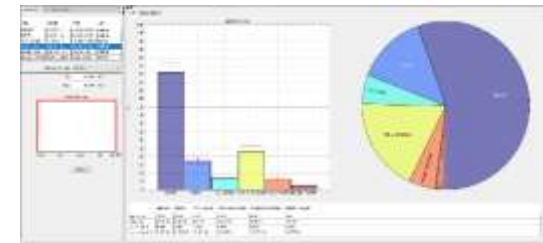
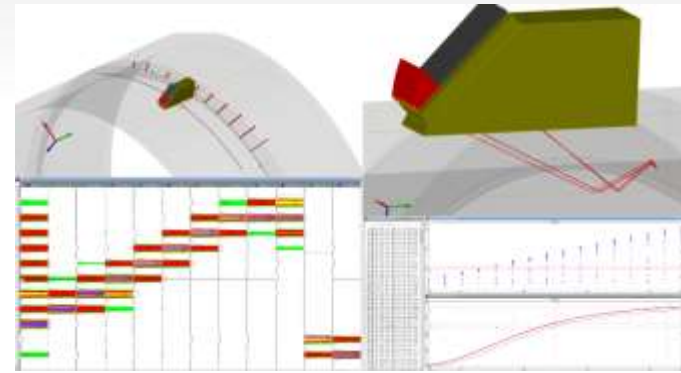
CIVA AUT Pipeline

CIVA AUT Pipeline :

Simulation for efficient girth welds AUT inspection performance demonstrations

CIVA AUT Pipeline includes:

- **Dedicated set of modules** that guide through the different steps of performance demonstration process:
 - **AUT Calibration:** Run channels calibration, verify set up and beam coverage
 - **AUT Sensitivity:** Define a range of variability for essential parameters and evaluate their influence
 - **AUT Size:** Evaluate sizing accuracy
 - **AUT POD:** Compute Probability Of Detection Curves
- **Generic CIVA UT modules** (for girth welds only) to **test, design and optimize** inspection procedures



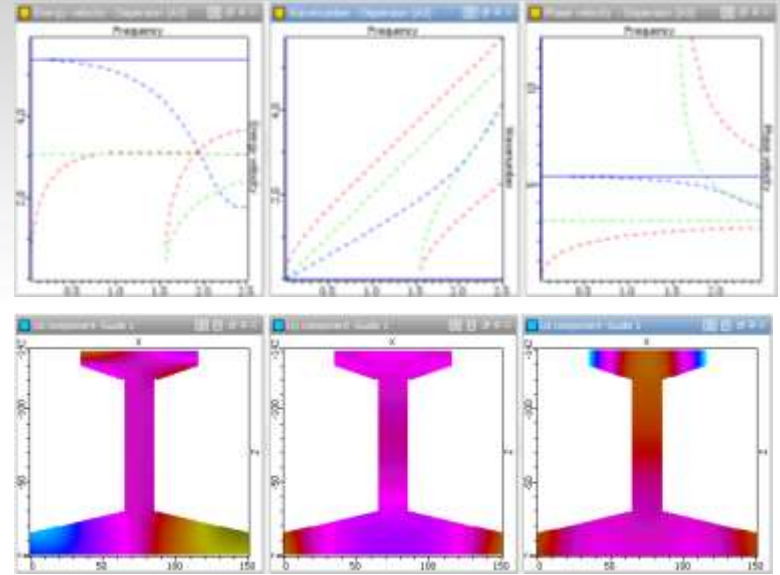
ZDM (Zonal Discrimination) and **TFM** methods available.



CIVA GWT

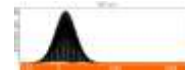
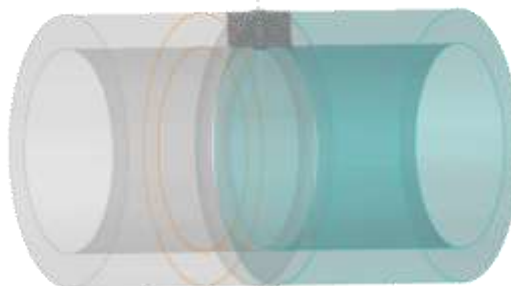
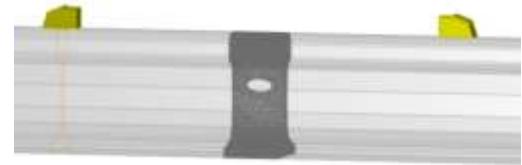
CIVA GWT includes:

- Dispersion curves computation
- Field computation
(Energy of modes emitted, displacement & constraints mapping in the cross section)
- Inspection Simulation tool
- Sensitivity analysis & POD curves computation



Covers:

- Various specimen geometries:
Planar, tubular, weld, Rail section,
- Piezo electric, Magnetostrictive or EMAT probes
- Single element or Arrays

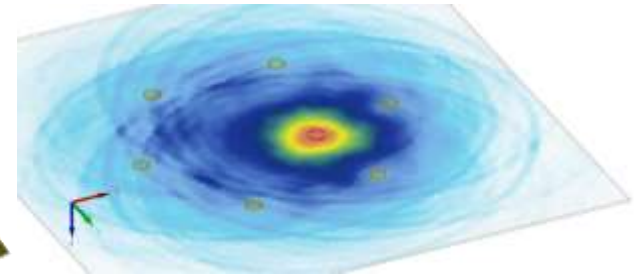
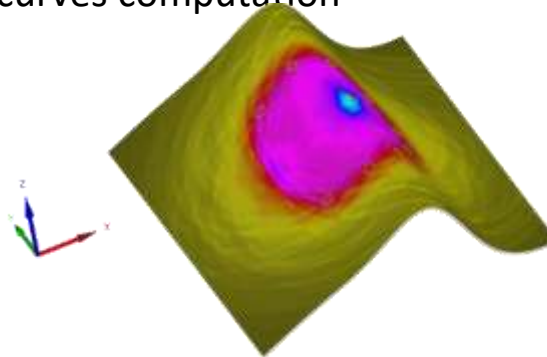
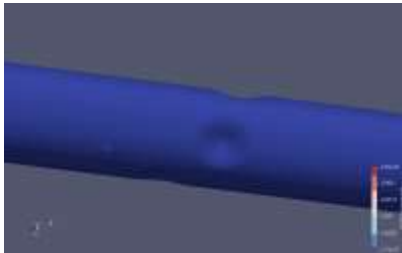
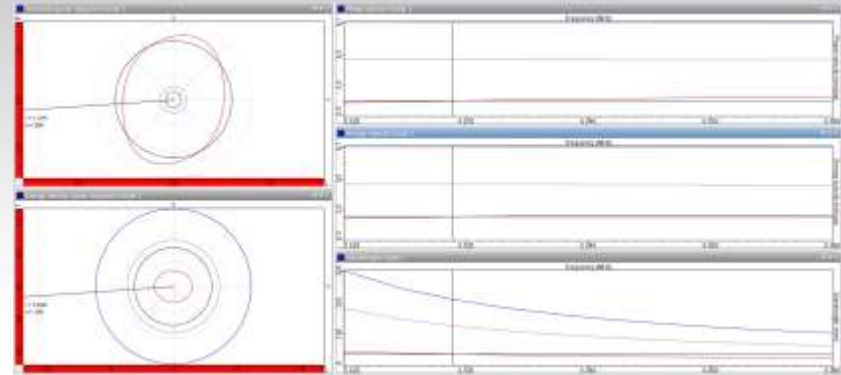




CIVA SHM

CIVA SHM by Guided Waves includes:

- Dispersion curves computation
- Inspection Simulation tool based on **3D Spectral Finite Elements** with very competitive performance
 - Simulations of individual sensors signals with/without defect(s)
 - Reconstruction imaging on 3D view
 - Local displacement/stress fields extraction
- Sensitivity analysis & POD curves computation



Covers:

- Metallic and composite plates, pipes and elbows
- Account for curvatures, stiffeners, sleeves
- Defects: Holes, Cracks, Delamination, Corrosion/Erosion, Inclusion

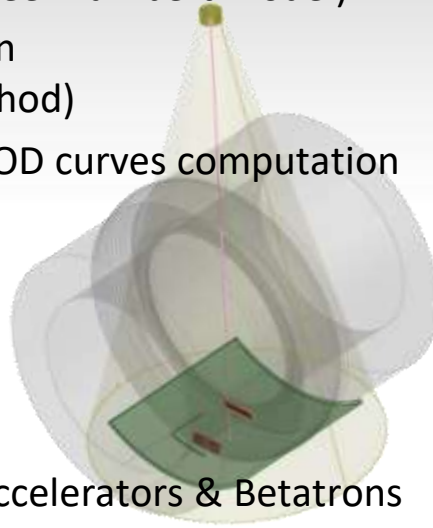




CIVA RT-CT

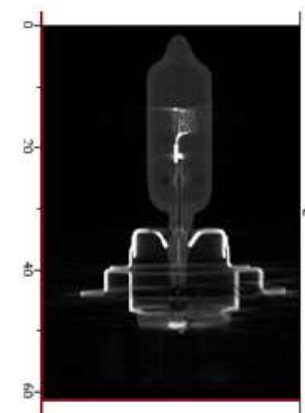
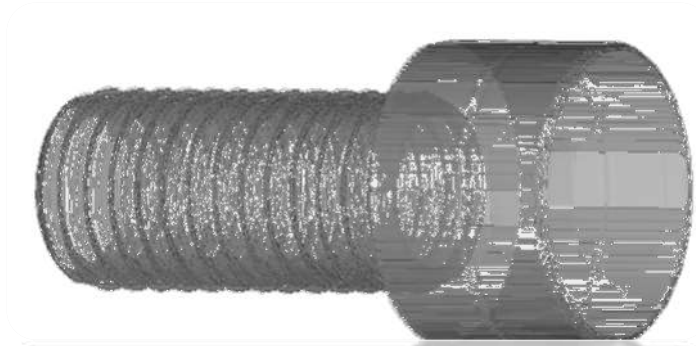
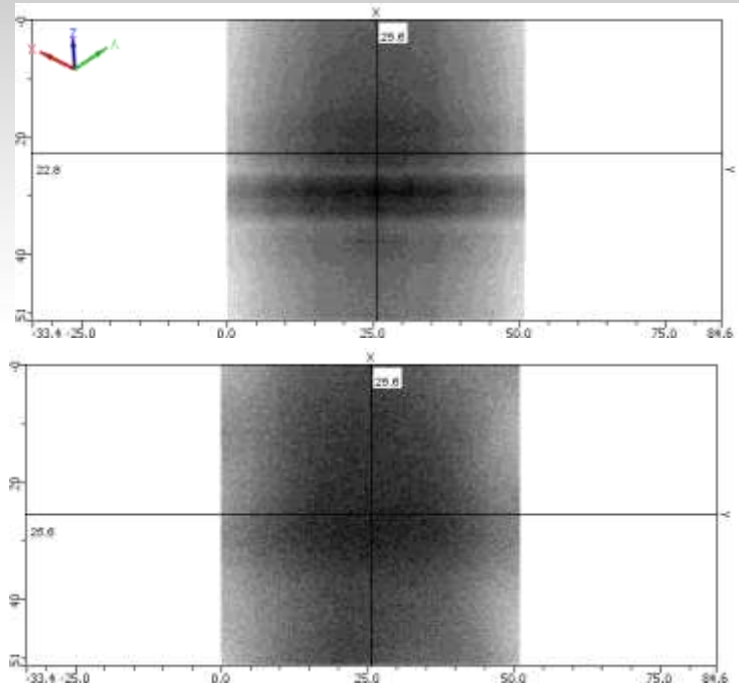
CIVA RT-CT includes:

- Radiographic image simulation
 - Direct radiation (Beer-Lambert model)
 - Scattered radiation (Monte-Carlo method)
- Sensitivity analysis & POD curves computation



Techniques covered:

- X-Ray
- Gamma-Ray
- High Energies: Linear accelerators & Betatrons
- Tomographic reconstruction (FDK, PixTV, SART algorithms)

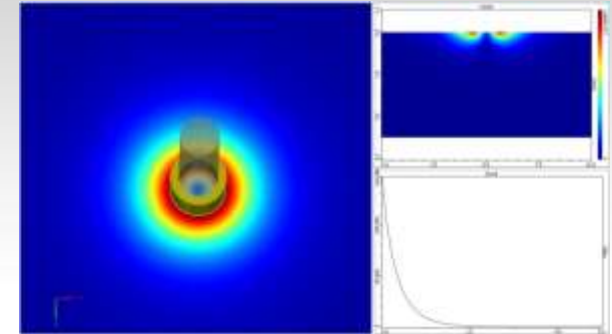




CIVA ET

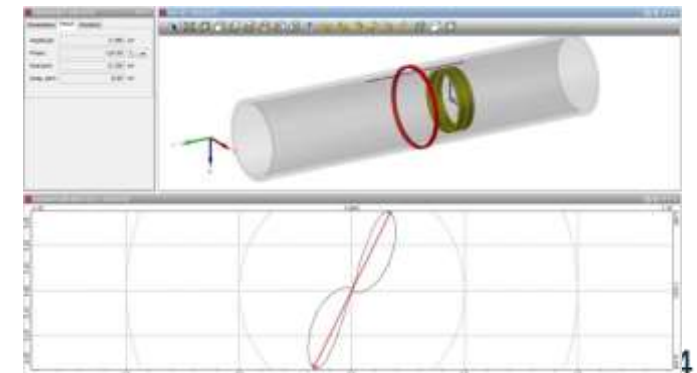
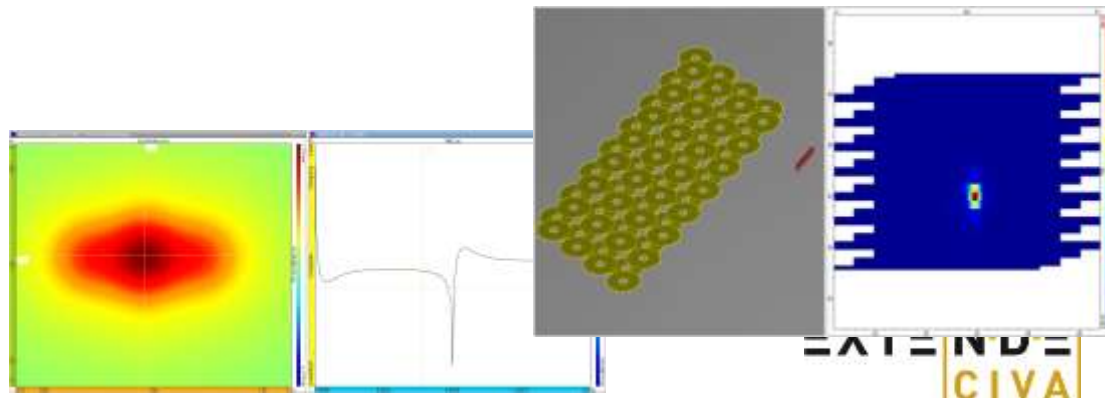
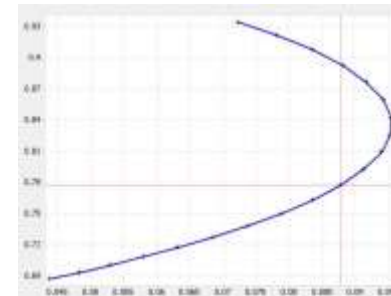
CIVA ET includes:

- Field Calculation tool
- Probe response (impedance diagram, lift-off signal)
- Inspection Simulation tool
- Sensitivity analysis & POD curves computation



Techniques covered:

- Conventional ET
- Eddy Current Array
- Remote Field Technique
- Pulsed Eddy Current

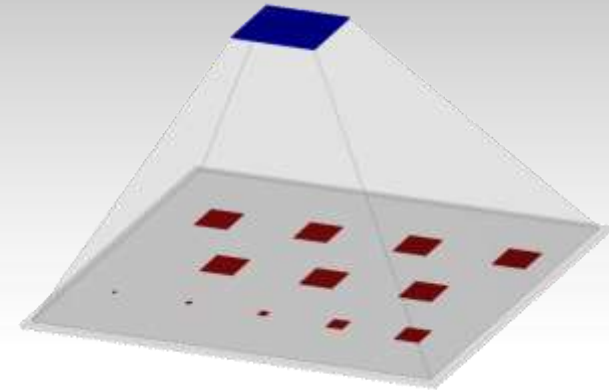




CIVA TT

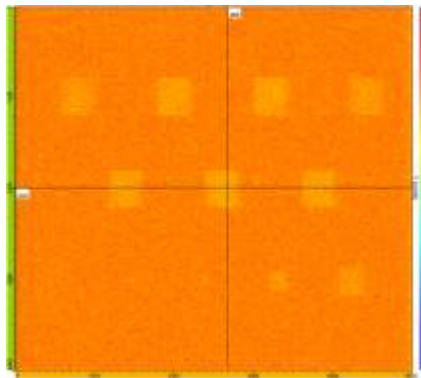
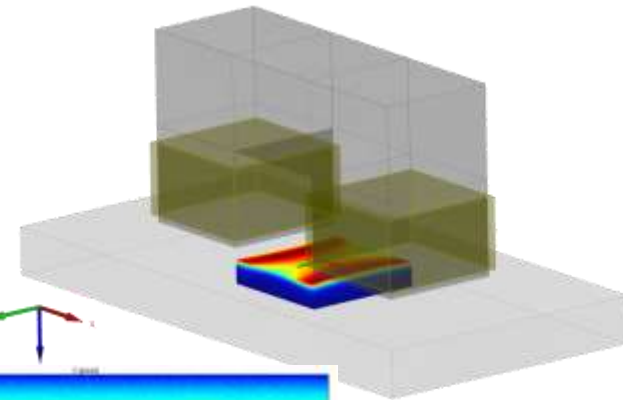
CIVA Thermography Testing includes:

- Optical Heating active thermography Inspection module
- 2D Computations
- Induction Heating module :
Computes power density induced in a conductive component excited by an inductor

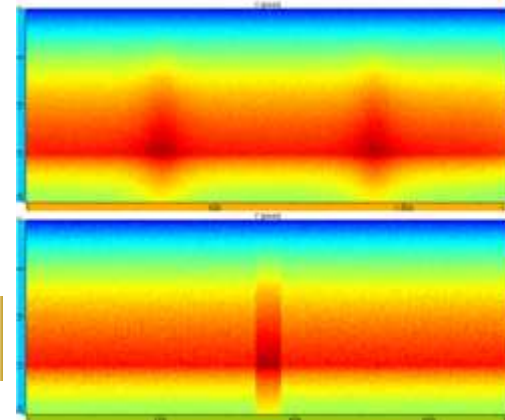


Covers:

- Flash, Transient and Lock-In Inspection techniques
- Planar / Multilayered profiles
- Planar, Cylindrical or “2D CAD” defect geometries



EXTEND
CIVA



RANSSEN 2024

el Bods, 9-11. juni 2024

page 11

NOT AN ADVERTISING FOR THE PRODUCT. BEST PRACTICE FOR THERMAL INSPECTION. APPROVED BY THE ASSOCIATION OF THERMAL



CIVA Data Science

| CIVA **DATA Science** : In order to use CIVA modelling to **train** and **test Artificial Intelligence** algorithms for **automated diagnosis**

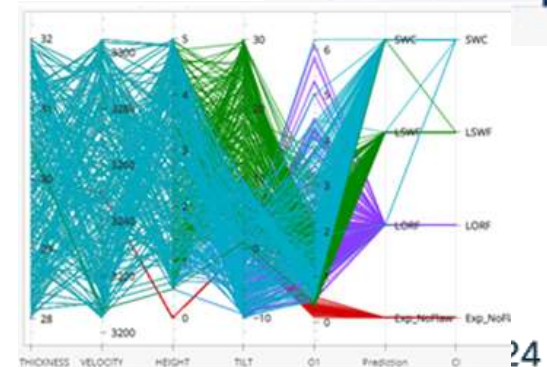
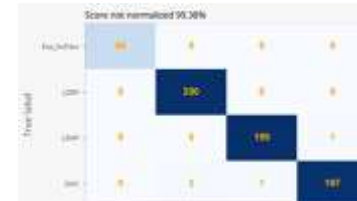
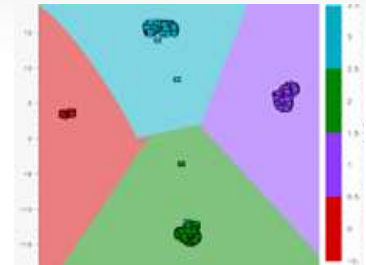
| CIVA Data Science features:

■ **Database management** tools:

Collect simulation & experimental data, Merge data bases, define relevant output criteria, customize them with Python scripts

■ **Classification and Detection diagnostic** models:

- **Train** Machine-learning tools on available databases
- **Try and Set** projection and classifier algorithms and parameters,
- **Visualize** classification results on relevant maps (2D plots, parallel plots, confusion matrices),
- **Test** the diagnostic model with experimental data.



| Compatible with all modules and works with CIVA Script



Why doing simulation for NDT ?

Design, optimize and prepare inspection:

- Standards alone cannot provide a ready-to-use efficient solutions for all applications
- Innovative solutions are promising....but does it work for my case ?
- I'd like to try before purchasing costly equipment !
- I'd like to understand better how it works !
- I have to tackle a challenging inspection (complex geometry and/or materials), and shall explore a lot of possibilities but cannot investigate everything with physical mock-ups and real tests.
- Which performance can I expect in terms of flaw detection and characterization ?

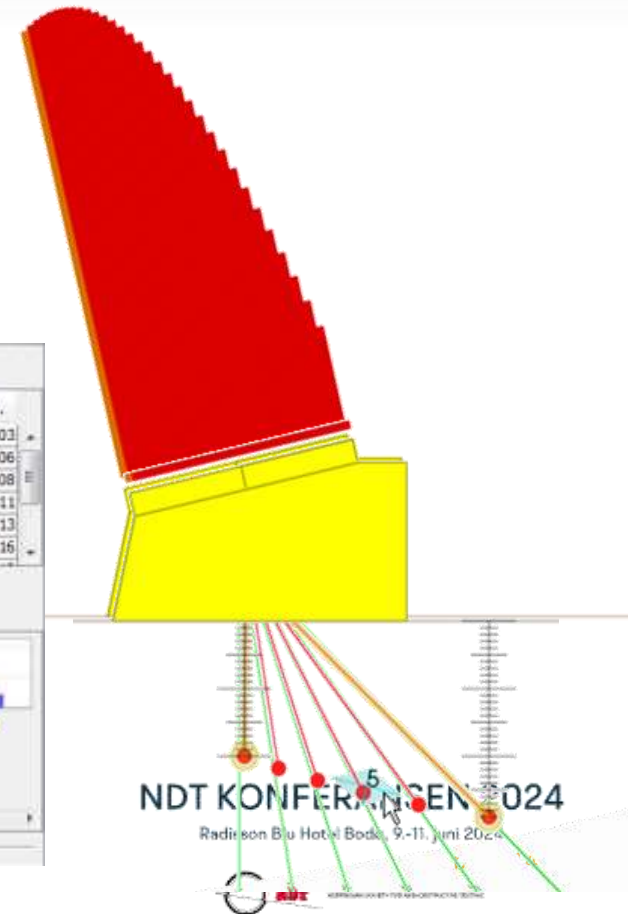
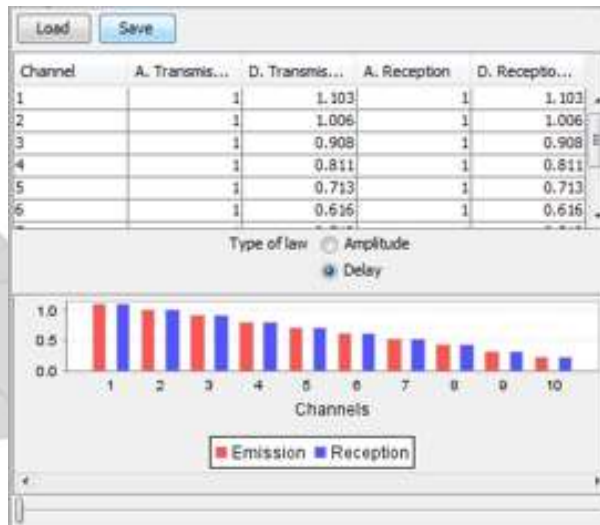
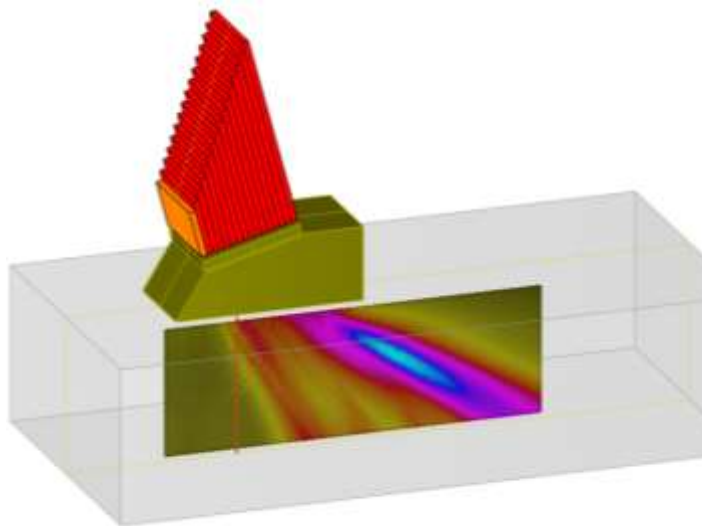
Simulation provide a **virtual design tool** to:

- Explore **feasibility**
- Help for fine tuning for **optimal performance** thanks to parametric studies
- Predict performances in terms of flaw detection and sizing
- Providing a lot of insights to understand better then better master the inspection technique
- It shall **dramatically save some iterations** and therefore **save time and money !**

Design and development

Example of a PA UT probe design:

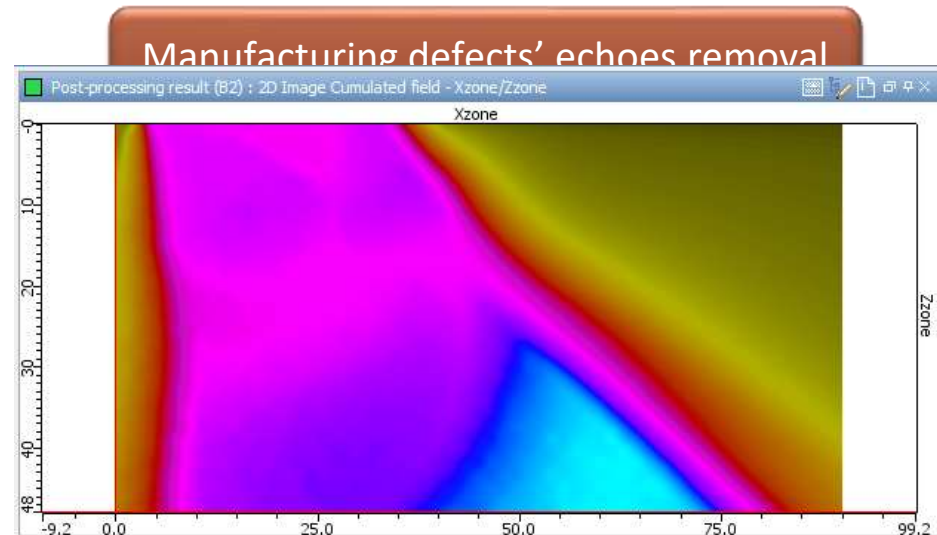
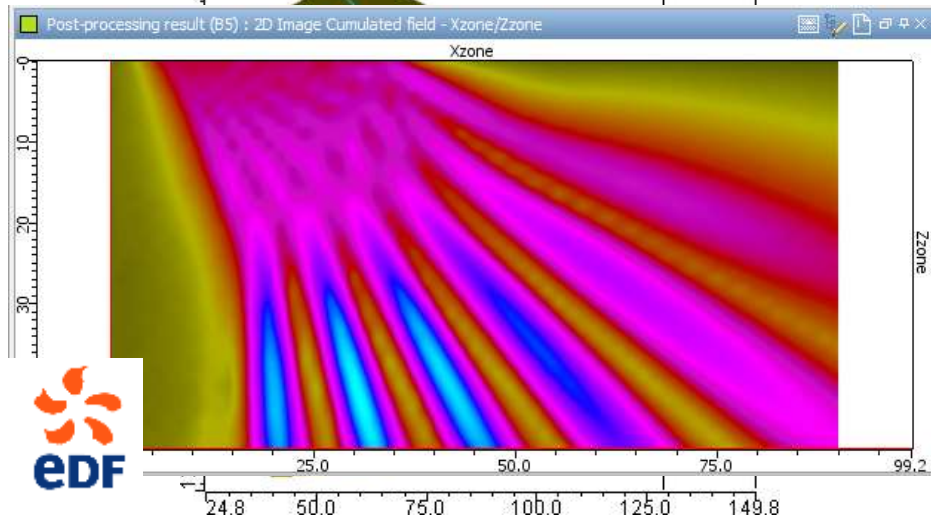
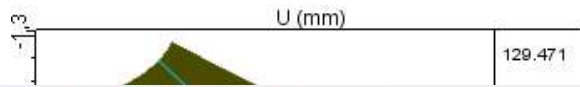
- You can't see the beam with trials
- Beam simulation to find out the best compromise aperture / number of elements / pitch to avoid grating lobes
- Compute focal laws vs requirements:
 - Beam spot size, angle, focal depth
 - Export delay laws and index points towards acquisition systems



Design and development

Example of a PA UT probe design :

- Define all channels to ensure sufficient coverage and good resolution (example with a sector scan)
- Anticipate defect response in the test piece: Visualize echoes
- Try innovative/alternative solutions:
Total Focusing Method to help detection and characterization



"Simulation study to improve detection of planar defects located under shrinkage cavities": S. Bannouf et al, ECNDT 2014

Sector scan example on a component including a lot of manufacturing defects (shrinkage cavity) hiding potentially critical planar flaws

NDT KONFERANSEN 2024

Radisson Blu Hotel Bodo, 9.-11. juni 2024

page 15

Why doing simulation for NDT ?

| Support reliability studies:

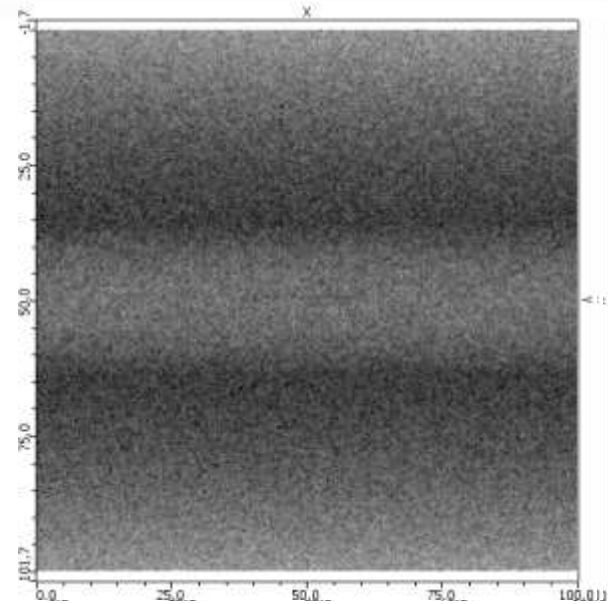
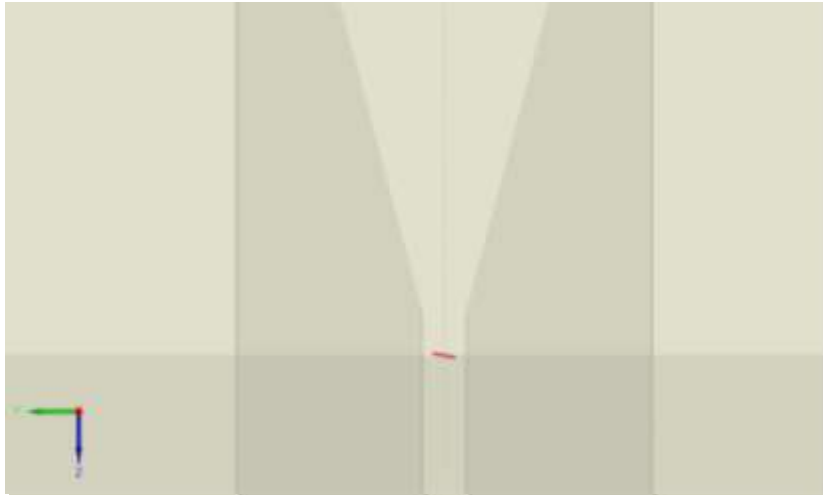
- I need to qualify or validate my procedure, I need to provide technical justifications of my NDT in the frame of a performance demonstration, I need to provide reliability indicator such as a Probability Of Detection value or curve
- All this requires to track the impact of influential/essential parameters, degradation factors, estimate worst case scenario, etc.

| Simulation provide tools to:

- Easily **monitor parameters** (such as flaw size, position, orientation, probe parameters, specimen parameters), studying cases that are **challenging to replicate experimentally**
- **Generating more data** and implementing a greater range of parameters
- Evaluate their impact through relevant curves, graphs and plots
- **Rank influential parameters** to select the most essential ones
- Extract sensitivity and reliability indicators such as “worst case”, **POD curve**, etc.

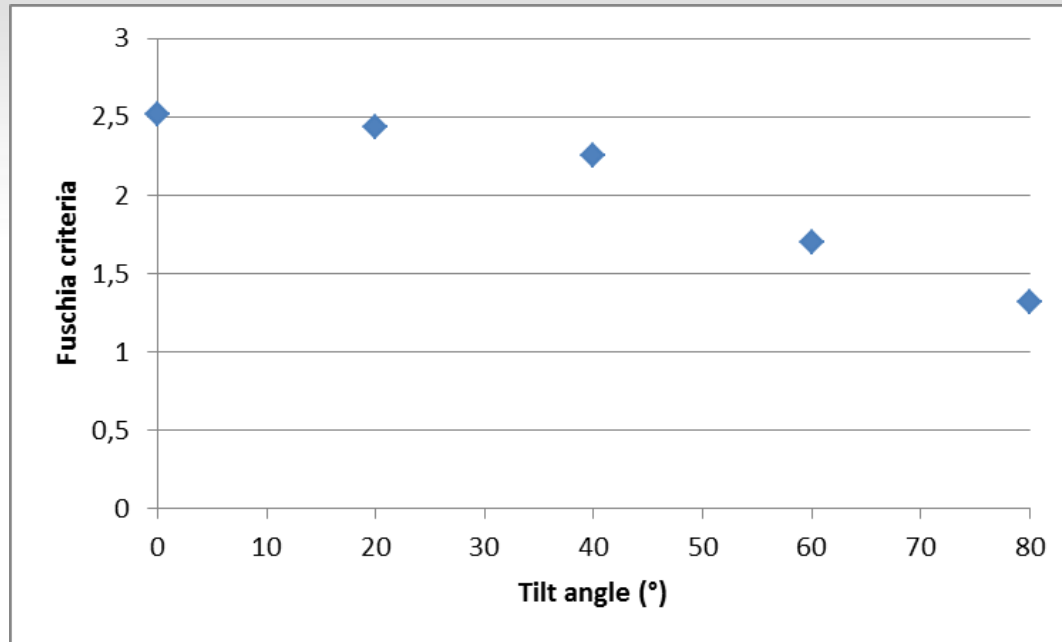
Sensitivity Study in RT

- Impact of the variation of the tilt angle from 0 to 80° of a rectangular notch :



Sensitivity Study in RT

Introduction of “detectability criteria” to quantify the detectability level in RT

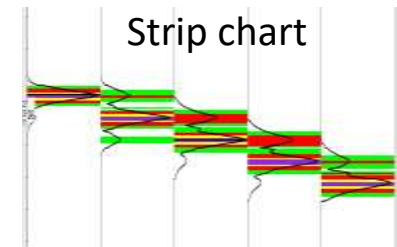
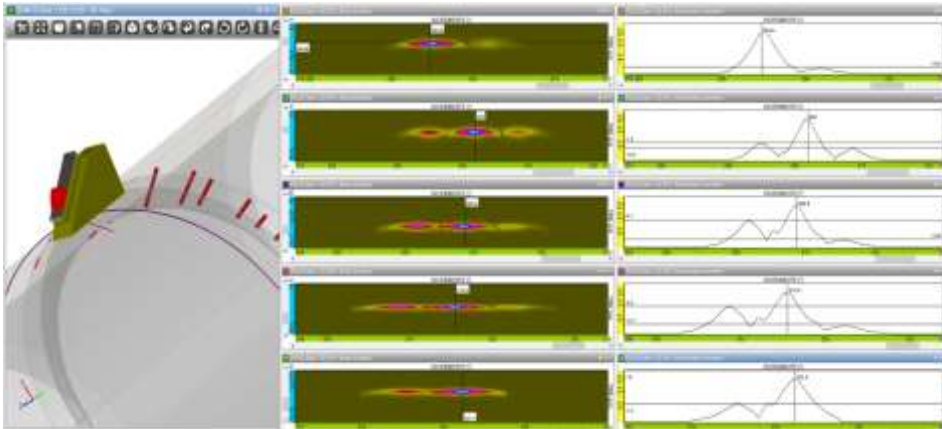


- Several criteria available in CIVA, here is displayed the “Fuschia” one (refer to CIVA user manual or “RT Modelling for NDT Recent and Future Developments in the CIVA RT/CT Module”, R.Fernandez et al, in the proceedings of WCNDT 2016)
- Here, the limit of detection is for a tilt angle around 60° (threshold is 1.5)

Performance demonstration in UT

AUT Pipeline Girth Weld inspection for Oil & Gas:

- State of the art: Inspection validation procedures are based on a substantial number of experimental and practical trials on representative welded mock-ups, such the use of calibration blocks with machined reflectors and defect coupons based on naturally induced or artificial flaws.
- Realistic induced flaws with specific size requirements is challenging and time and cost consuming to be produced during the validation works. In addition, multi macro slicing for actual height determination is required and potentially treatment of outliers.
- **Simulation can help to do more, better and cheaper !**
 - **Step 1 : Simulate the calibration mock-up**



Reference amplitudes are computed for each channel using the reference reflector to normalize the simulation amplitude with regards to the experimental procedure.

Performance demonstration in UT

AUT Pipeline Girth Weld inspection for Oil & Gas:

- **Simulation can help to do more, better and cheaper !**

- **Step 2 : Sensitivity study**

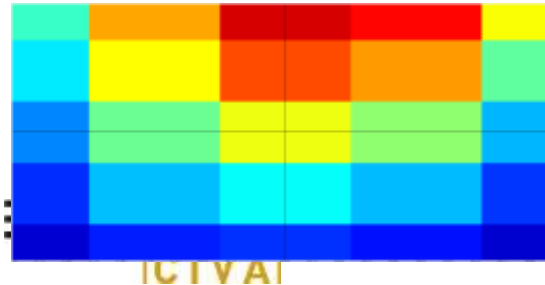
Example of essential variables (for each channel)

- Thickness of the specimen (e.g. +/- 1mm)
- Material (Wave velocity) (e.g. +/- 5%)
- Position of the probe (e.g. +/- 1mm)
- Orientation of the defect (e.g. +/- 5°)
- Depth (e.g. +/- 4mm)
- Position of the defect
- Height of the defect (example : 0.2 to 5mm)

- **Limitations of single parameter variations:**

- No idea about potential parameter interactions.
 - Full factorial design with 4 values and 10 parameters : $\sim 4^{10}$ simulations to run !!!

Intensive simulations are required for statistical studies:
Up to 10 parameters can be involved in the study
→ **Use of metamodels**



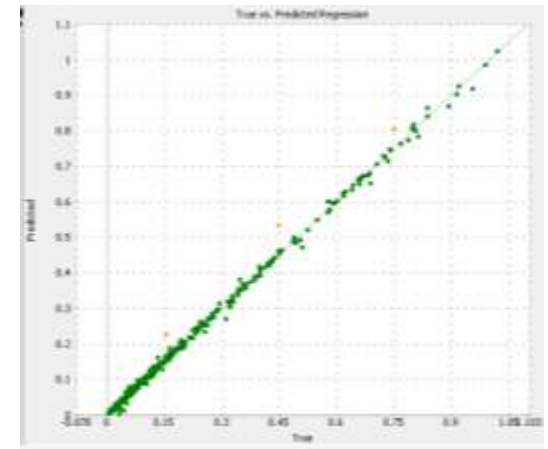
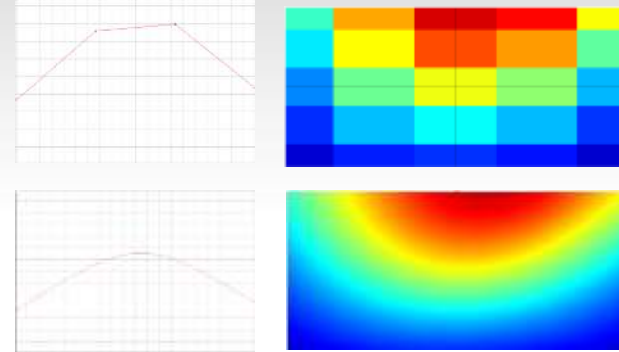
NDT KONFERANSEN 2024

Radisson Blu Hotel Bodø, 9.-11. juni 2024

Performance demonstration in UT

AUT Pipeline Girth Weld inspection for Oil & Gas:

- Metamodeling capabilities included in CIVA
 - Based on an initial set of computed cases with variable parameters: The “database” (discrete grids).
 - Application of smart interpolation algorithms to build a **surrogate model** which provides a **continuum** of results for **all parameters combination**.
 - Once available, you can explore multiple scenarios in the defined range
→ **“Real time” simulations, massive data** production.
 - Metamodels needs a simulation database based on physical models with enough samples and metamodel “error” shall be assessed prior to use.



Performance demonstration in UT

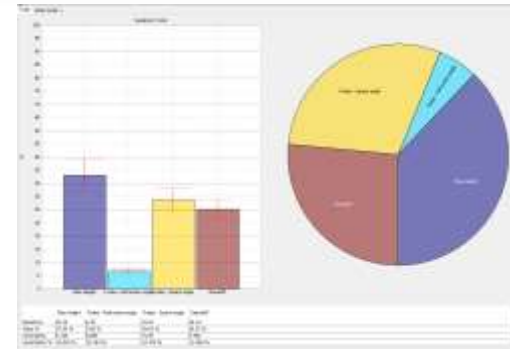
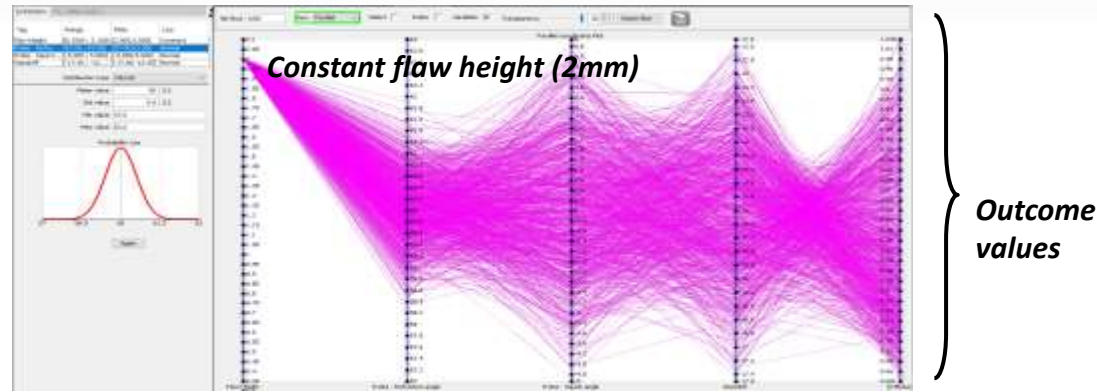
| AUT Pipeline Girth Weld inspection for Oil & Gas:

You can explore any combination of parameters' values, i.e., any inspections scenarios:

- **Multidimensional analysis** with parallel plots

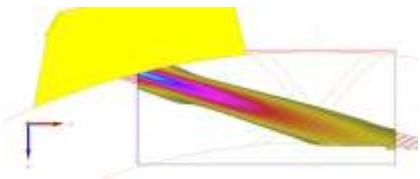
Impact of 4 parameters on signal amplitude for N trials (here 1000)

- Essential parameters' "ranking" : Sobol Indices:



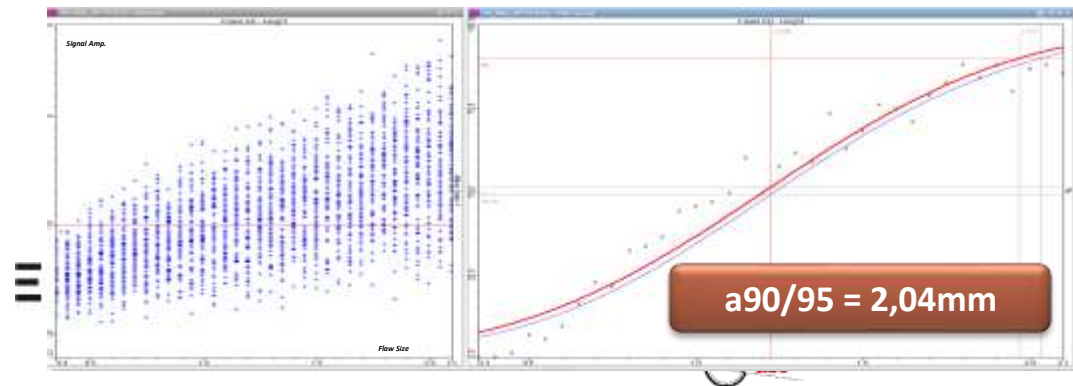
Gaussian laws for 3 other parameters)

- **POD Curves:** very large sampling
You can try different hypotheses for parameters



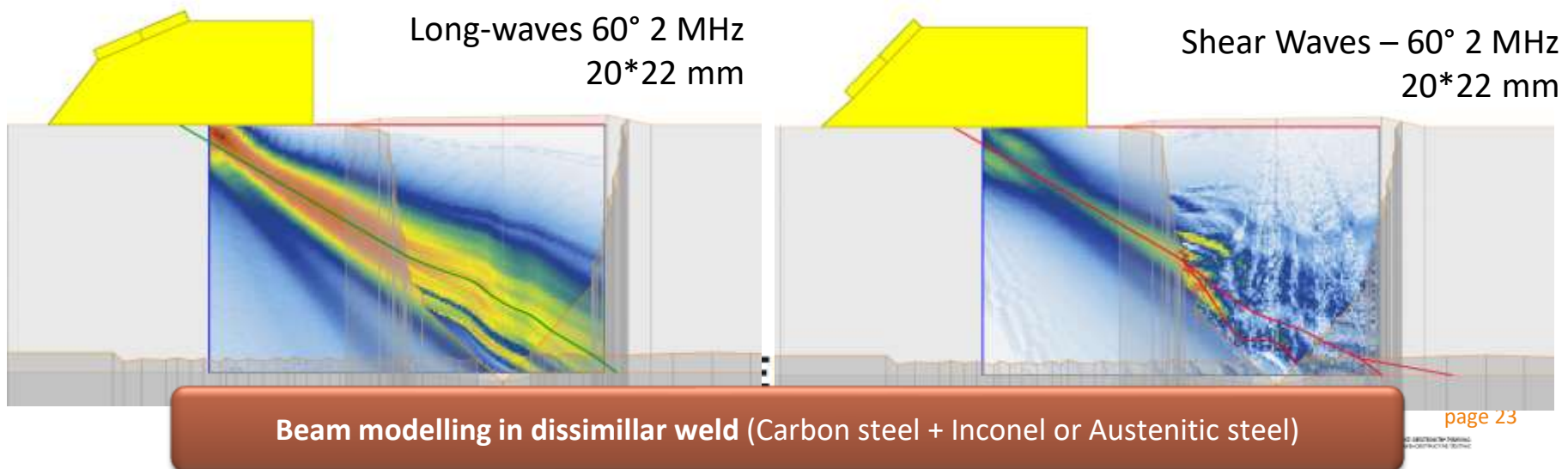
Example : S60° channel

Target Zone: Lower weld volume



Why doing simulation for NDT ?

- | Helps understanding and illustrating:
 - I have complex results to analyze from the field and make my diagnosis
 - I need to convince my customers/colleagues
 - I need to train my staff about NDE physics
- | Simulation provide tools to:
 - Reproduce field situations and explore different scenarios that might explain a signal in order to **confirm or disprove a diagnosis**
 - **Illustrate physics** of NDT with images (UT beam, X-ray photon path, eddy current distribution, ultrasound modal analysis, etc.)



Simulation software validation

- | CIVA software development goes along with extensive tests & validation works:
 - To demonstrate applicability of new models when they come out,
 - Quality Assurance and non regression tests between each release,
 - Annual participation to WFNDEC benchmarks (since more than 10 years for CIVA UT and ET) published at QNDE conferences (see wfndec.org),
 - In the frame of industrial projects and collaborations, or made by users themselves.
- | Some of these works lead to communications, important literature can be found
- | Numerous additional validation cases have been published on EXTENDE website:
www.extende.com
 - <http://www.extende.com/objectives-of-the-experimental-validation-ut>
 - <http://www.extende.com/objectives-of-the-experimental-validation-et>
 - <http://www.extende.com/objectives-of-the-experimental-validation-rt>

Conclusion

- Simulation cannot replace all real trials on mock-ups but improves cost-efficiency of NDT at different stages of the process
 - Design and qualification of inspection methods
 - Preparation of inspection
 - Expertise
 - Training
- | Requires appropriate tools and experimental validations
- | Requires appropriate training for users
- | Want to see the CIVA software? Come at the booth for a demo.

Thank you !

| QUESTIONS ?

Fabrice FOUCHER
fabrice.foucher@extende.com
www.extende.com

EXTENDE
CIVA