Performance demonstration of AUT Pipeline girth welds using simulation and the new CIVA AUT Pipeline software

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Abstract: The full qualification and validation procedure for AUT Pipeline girth welds inspection requires a large number of experiments on representative welded mock-ups, with machined or seeded defects for the quantification of the AUT system, set up and procedures performances. The performances demonstration is expressed with the Probability of Detection and Sizing accuracy qualification as functions of the flaw height. To reduce experimental qualification and validation time and costs, the simulation is today considered and accepted in many industries (such as nuclear and aeronautics) as a attractive and quantitative solution and a relevant aid for the constitution of the qualification and / or validation technical dossier.

Numerical NDT demonstration of performance means multi-parameter sensitivity studies, taking into account the propagation of uncertainty and statistical analysis of the variability of the AUT essential variables. This communication will present the features of the new CIVA AUT Pipeline software developed by CEA, and already assessed by a multi-sponsors project including oil and gas operators , pipelay installation contractors and AUT services vendors in order to match the software capabilities with the market expectations.

CIVA AUT Pipeline proposes, for a given system, set up and procedure (ZDM or TFM approach), a numerical quantification of the effects of the essential variables on the AUT performances (PoD and sizing accuracy). The various qualification steps from calibration up to performances quantification will be presented with the final objective to reduce and to optimise the design of experiments on seeded defects coupons in order to reduce qualification and validation cost and schedule.

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Performance demonstration of AUT Pipeline girth welds using simulation and the new CIVA AUT Pipeline software

DE LA RECHERCHE À L'INDUSTRIE

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OUTLINE

- AUT Pipe Girth Weld inspections context
- The steps of an AUT Pipe GW inspection validation
  - Calibration
  - Sensitivity Analysis (Essential variables)
  - POD (Model Based POD - MAPOD)
  - Sizing accuracy assessment
- CIVA AUT Pipeline software
- Conclusion

Conventional uses of simulation

- Assessment and optimization during the design stage
- Support for a better understanding of unexpected results during the trial runs

Performance demonstration using simulation

Advantages of simulation

- **Reducing costs.**
- **Generating more data and implementing a greater range of parameters.**
- **Studying cases that are challenging to replicate experimentally.**
- **Facilitating interpretation of results**

AUT Pipe Girth Weld inspections for Oil&Gas

State of the art (validation procedures) :

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.

- procedures of validation are usually at the critical path of projects execution
- the number of data sets may be limited

In this context, the use of simulation opens large perspectives and benefits

AUT Pipe Girth Weld inspections for Oil&Gas

JIP Risk based AUT validation

2018 - 2022

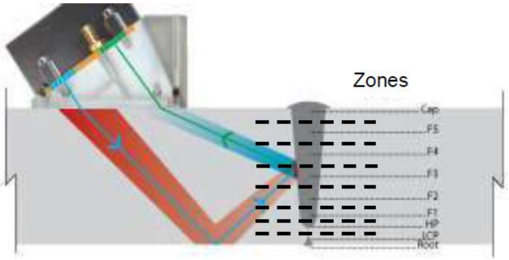
Objective:

- Industry guidelines for performance assessment: Compliance with industry guidelines, such as DNV-ST-F101, is essential for ensuring consistent and reliable pipeline girth weld NDT quality control.
- Integration of advanced techniques and simulation tools: Embracing new advanced techniques and simulation tools can enhance the performance assessment process and open avenues for further development.
- Efficient methodology : Developing a methodology that efficiently determines the appropriate scope of AUT and NDT techniques for each application is essential for optimizing quality control activities within AUT validations.

Revision of DNV-RP-F118 (in progress), including a Guideline for simulation as part of the AUT validation

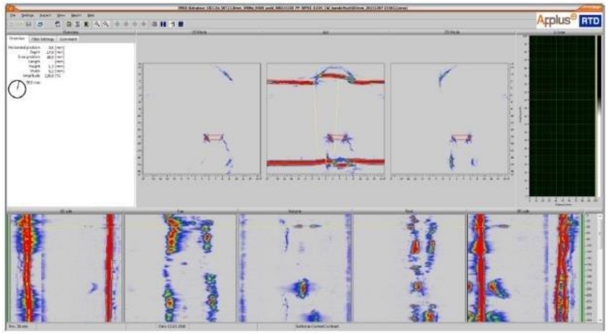
Techniques for AUT Pipe GW inspection and AUT Procedures

ZDM



Widespread and standardized technology
A large background and skills
But validation still costly… and could be further optimized by the use of simulation

TFM

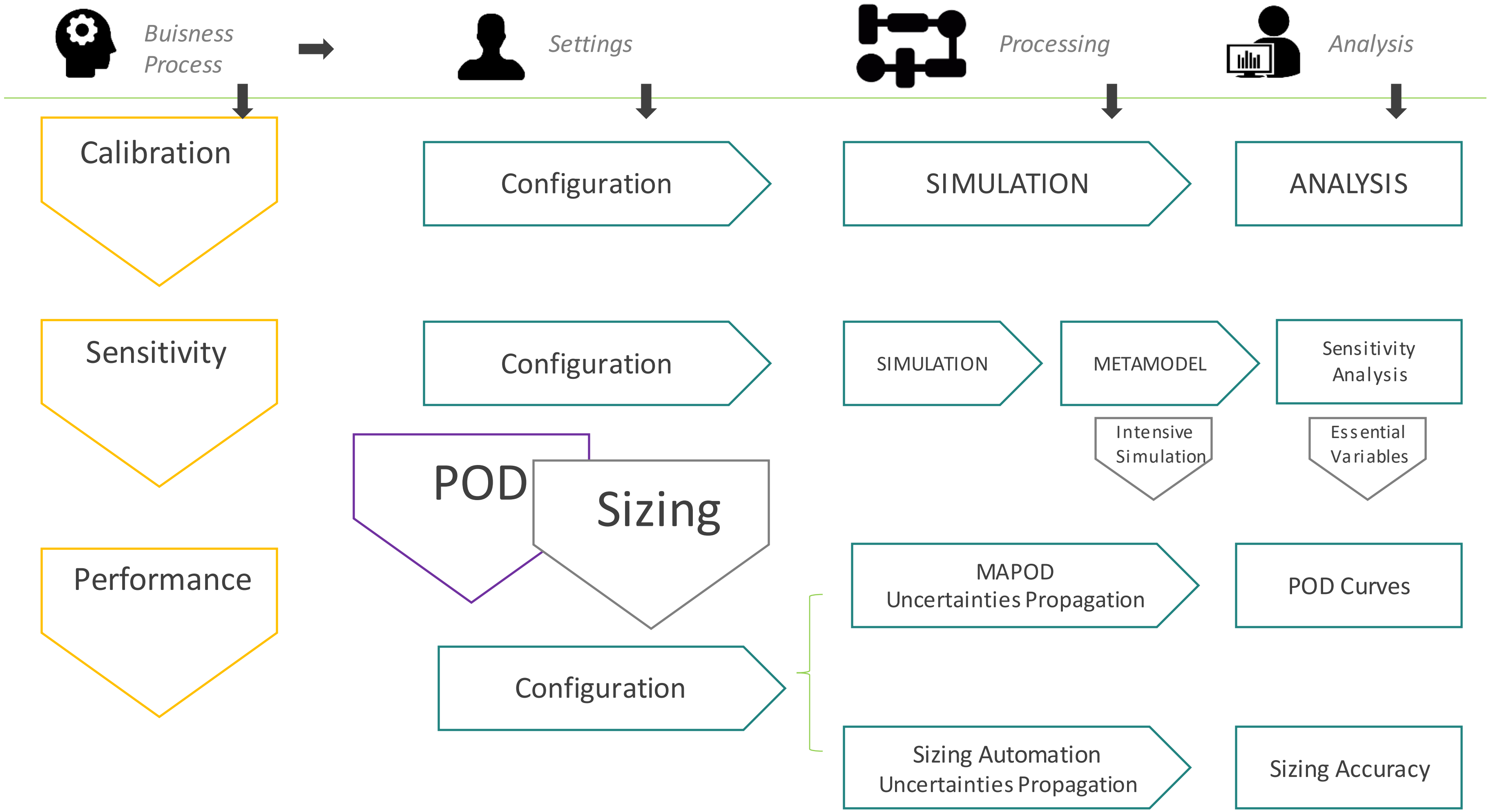


IWEX from ApplusRTD

A promising technique
Better productivity and better efficiency are already admitted (Example : IWEX from Applus RTD)

A new technique is also an opportunity to modify the standards and may confirm the advantage of simulation as a support to this major progress in the field of NDT for AUT Pipe GW inspections

The steps of an AUT Pipe GW inspection validation



STEP1: Simulation of the calibration process

Calibration: the first step of the inspection process, well mastered and reproducible.
=> A perfect use case to start with simulation: available data, controlled inputs.

- Collection of all inputs required for simulation (specimen, weld, material, probe, wedge, delay laws …)

- Several topics can be considered

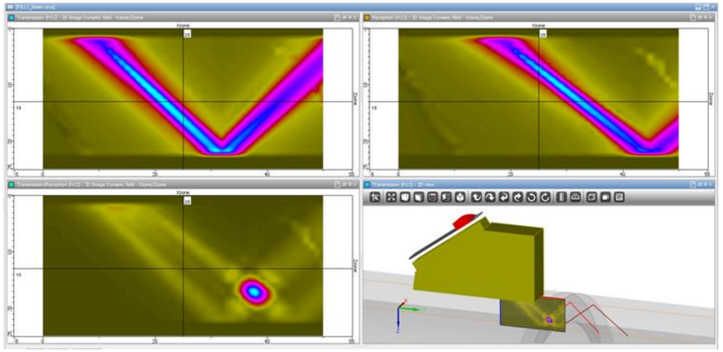
  - ➢ Beam computation and Sensitivity Coverage : verification of the beam => Focal laws, Probe, Wedge …
  - ➢ Inspection simulation on the calibration block : calculation of the reference amplitude and assessment of the reliability of the model (using cross validation with several models or experimental comparisons)
  - ➢ Calibration sensitivity : impact of uncertainties of the calibration procedure

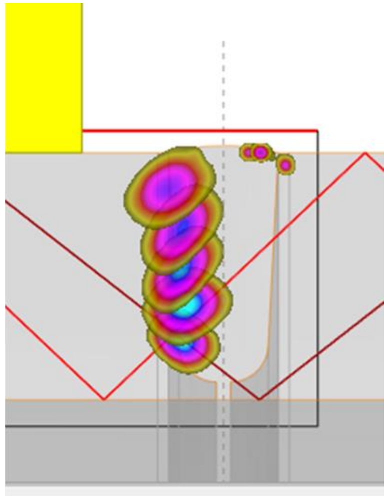
The main purpose is to compute the reference amplitude (“0dB”) that will be used for further studies and quantitative comparisons
⇒ An essential aspect for quantitative assessment using simulation

- Calibration configurations are well suited for checking
  - The inputs of the configuration (Probe, Delay Laws, Specimen and Material properties… on nominal conditions)
  - The reliability of the model (easier comparison with experiment)

STEP1 : Calibration - Beam computation and Sensitivity Coverage

This first step allows to
- check that Inputs and Results are coherent
- contribute to the justification of the method (weld coverage insonification)

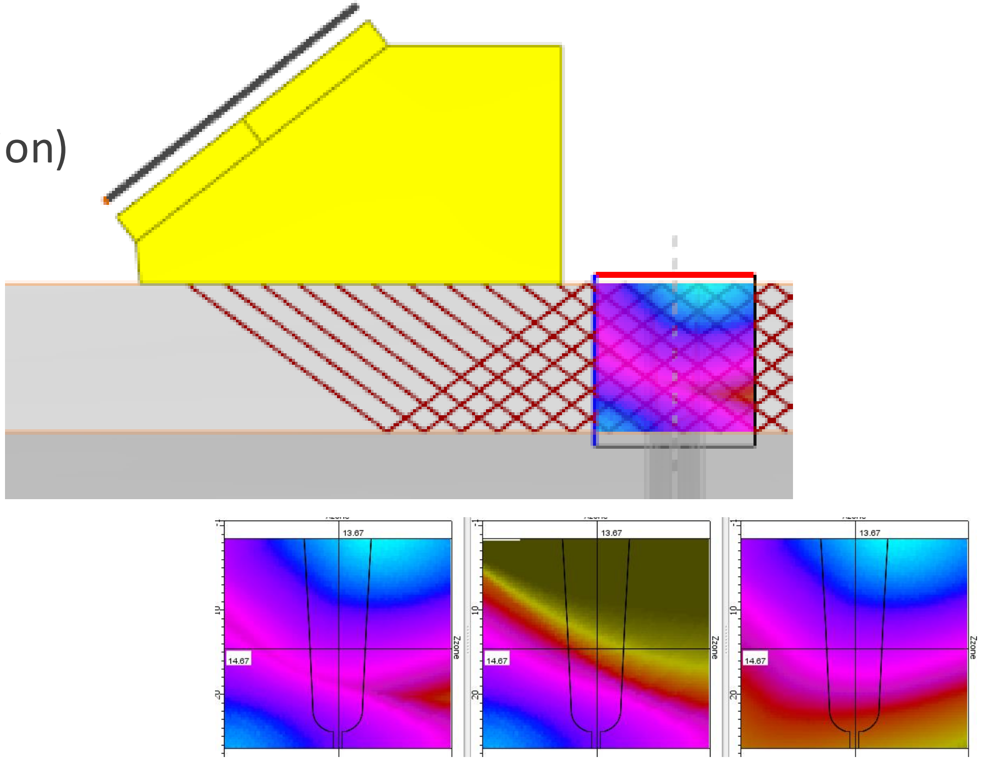




Beam computation
(T, R and T/R)

TR coverage for
All Fill Channels

ZDM Multi channels coverage



TFM multi modal coverage

For TFM, the calculation at each point of the zone is performed by applying a specific local focusing law estimated from the times of flight determined for each element of the probe

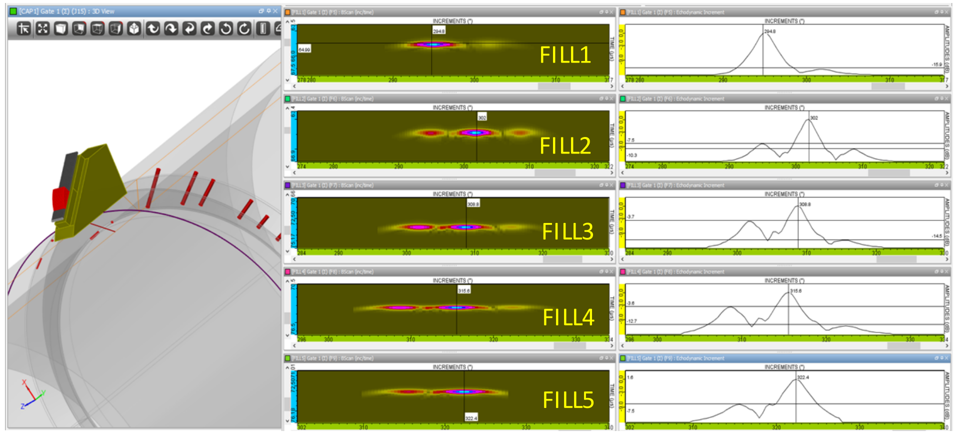
STEP1 : Calibration

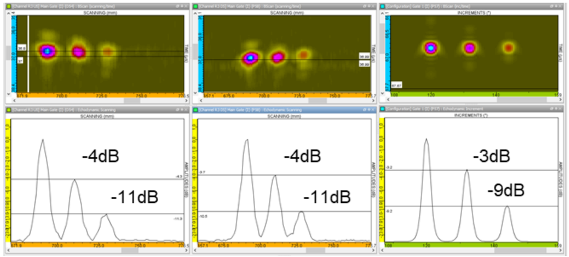
Inspection simulation on a calibration block

- **Check that Inputs and Results are coherent**
- **Contribute to the justification of the method**
- **Compute the reference amplitude for each channel**

- Reference amplitudes are computed for each channel using the reference reflector
- It allows to
  - Normalize the simulation amplitude with regards to the experimental procedure
  - Compare simulations of a same channels with different defects or values of essential variables

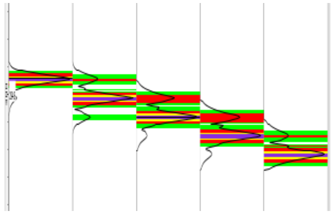
- Reference amplitude has a direct impact on quantitative studies based on amplitudes values and thresholds (Sizing, POD …)



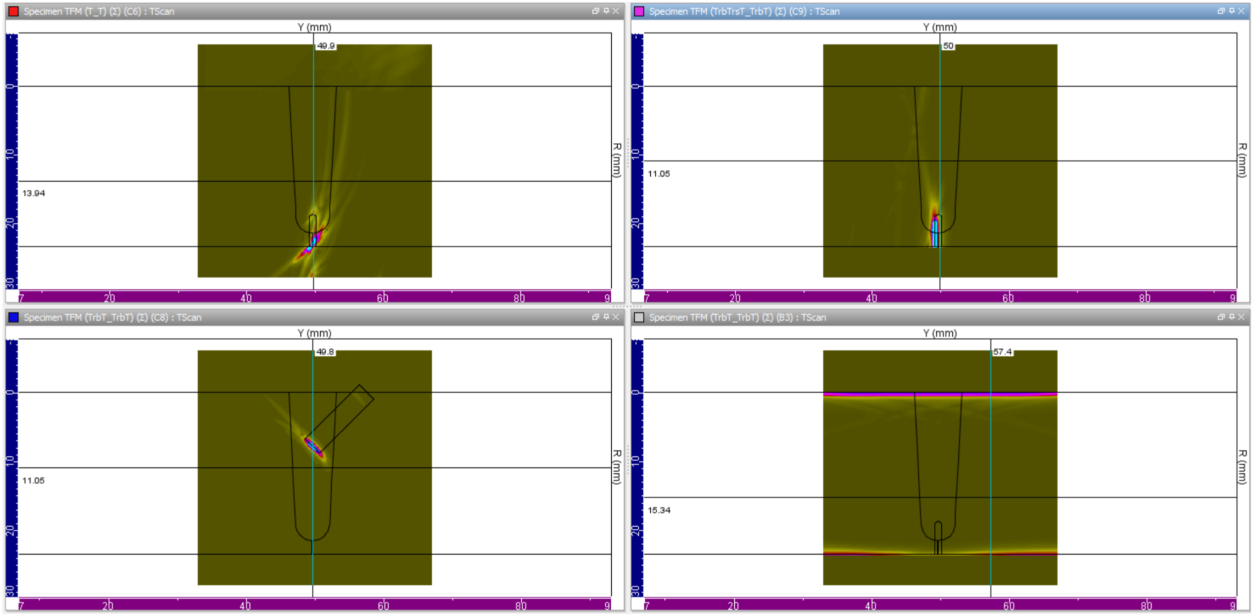


US DS SIM

ZDM



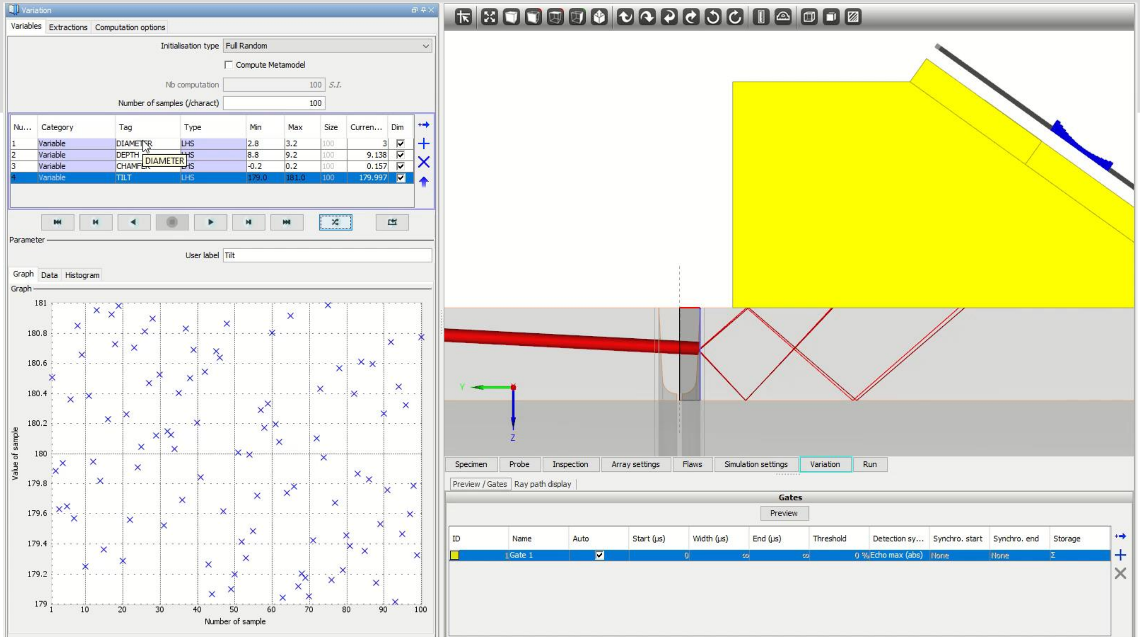
Strip chart



TFM

STEP1 : Calibration sensitivity

- Calibration sensitivity : impact of uncertainties of the calibration procedure
- Level of confidence of the reference amplitude



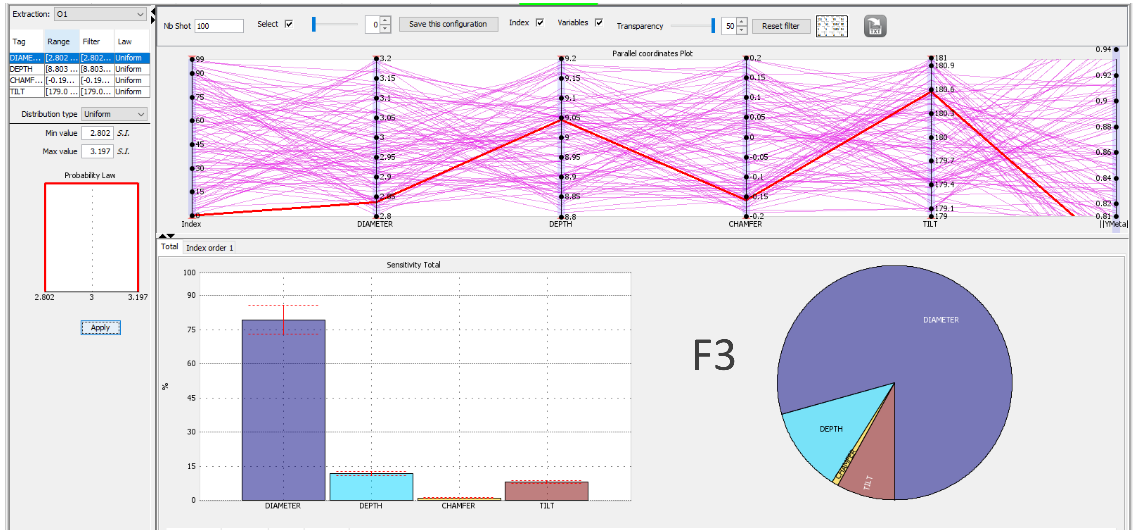
DNV recommendation

E.2.5.7 The calibration block shall be identified with a hard stamped unique serial number providing traceability to the examination work and the material source of supply for which the standard was manufactured. Records of the correlation between serial number and wall thickness, bevel design, diameter, and ultrasound velocity shall be kept and be available.

The machining tolerances for calibration reflectors are:

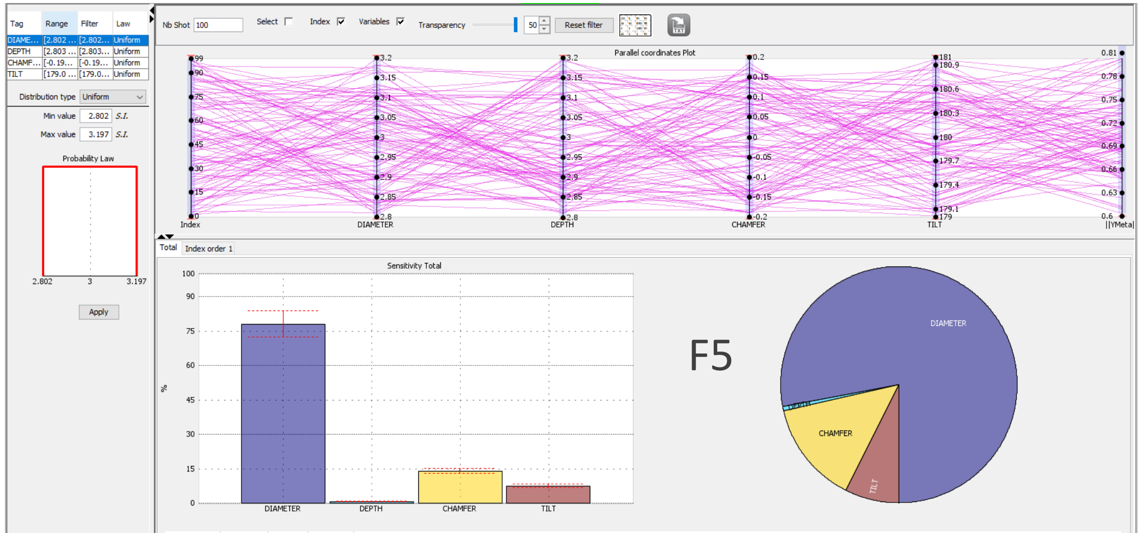
-	Hole diameters	± 0.2 mm
-	Flatness of FBH	± 0.1 mm
-	All pertinent angles	± 1°
-	Notch depth	± 0.1 mm
-	Notch length	± 0.5 mm
-	Central position of reference reflectors	± 0.1 mm
-	Hole depth	± 0.2 mm.

E.2.5.8 The lateral position of all reference reflectors shall be such that there will be no interference from adjacent reflectors, or from the edges of the blocks.



	DIAMETER	DEPTH	CHAMFER	TILT
Sensitivity	79.21	11.61	0.94	8.00
Value %	79.40 %	11.64 %	0.94 %	8.02 %
Uncertainty	6.284	0.935	0.087	0.623
Uncertainty %	7.933 %	8.054 %	9.259 %	7.786 %

1.6dB



	DIAMETER	DEPTH	CHAMFER	TILT
Sensitivity	78.02	0.60	14.00	7.40
Value %	78.00 %	0.60 %	14.00 %	7.40 %
Uncertainty	5.786	0.063	1.159	0.676
Uncertainty %	7.417 %	10.418 %	8.275 %	9.132 %

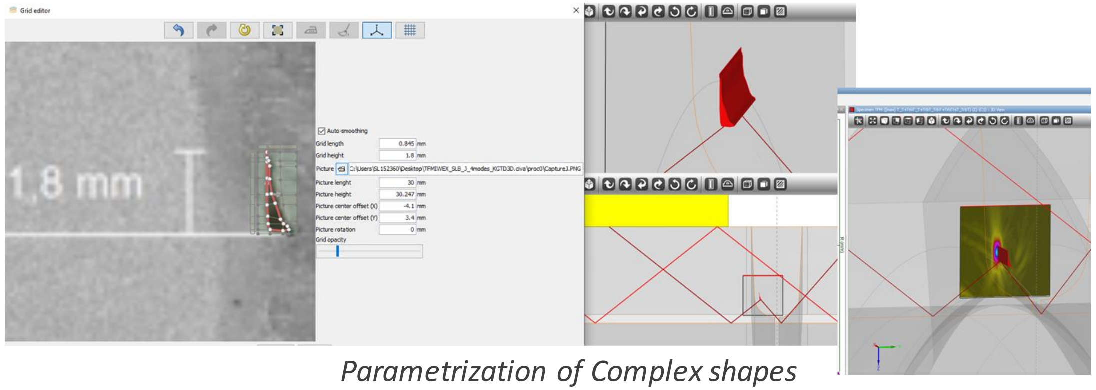
2.6dB

STEP3: Essential variables and sensitivity analysis

Domain of variation

The justification dossier includes an identification and an ranking of the essential variables.
Simulation makes it possible to take into account a large domain of variabilities

Essential variables :
- Thickness of the specimen (+/- 1mm)
- Material (Wave velocity) (+/- 5%)
- Position of the probe (+/- 1mm)
- And more …



Parametrization of Complex shapes
For variations studies

Defect variables
- Orientation of the defect (+/- 5°)
- Depth (for each channel +/- 4mm from the nominal value of the calibration reflector)
- Position of the defect (depending of the Weld and channels)

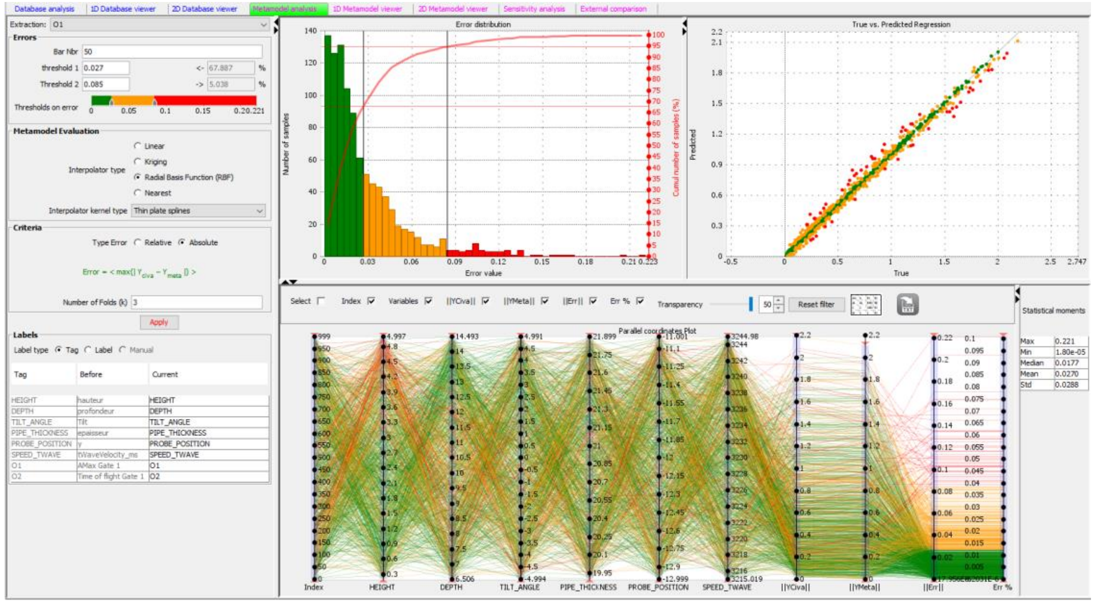
Characteristic value
- Height of the defect (example : 0.2 to 5mm)

⇒ Computation of a set of simulations with LHS drawing law in the domain of variation
⇒ This set of simulation will be used to generate metamodels => number of simulation between 500 to 2000 (metamodels accuracy has to be checked before use for statistical studies)

STEP2 : Simulation and Metamodeling

- Intensive simulations are required for statistical studies
  - Up to 10 parameters can be involved in the study (essential variables + defect size, orientation and position)
  - Impact of statistical laws have also to be assessed (capability to evaluate on several experimental designs , level of confidence)
  - Generation of a metamodel allows to compute thousands of evaluation in very short time (less than 1 seconds)

- Metamodels accuracy
  - Depends on initial database (learning stage) and interpolation algorithm
  - Depends on number of inputs
  - Dedicated tools are required for metamodel accuracy assessment before using it for the continuation of the study



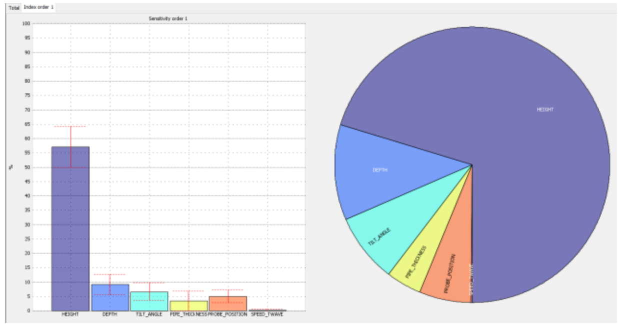
STEP3 : Essential variables and sensitivity analysis

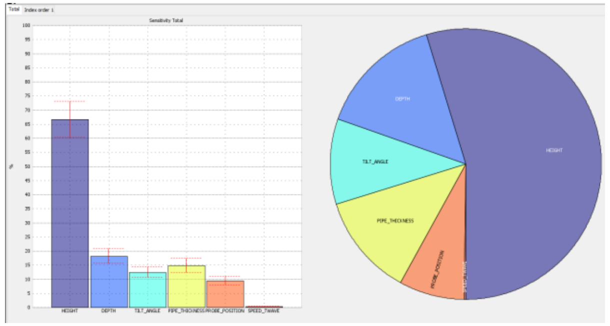
- Sensitivity analysis requires a large amount of evaluations => Only possible by using simulation
- Sensitivity analysis allows to assess the impact of essential variables
  - One by One (first order and intuitive)
  - Combined (order n)

- Can be applied
  - channel by channel
  - for the entire procedure

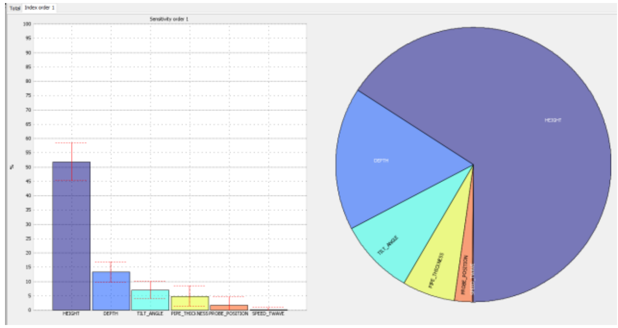
Sensitivity Analysis Order 1 | Sensitivity Analysis Order n

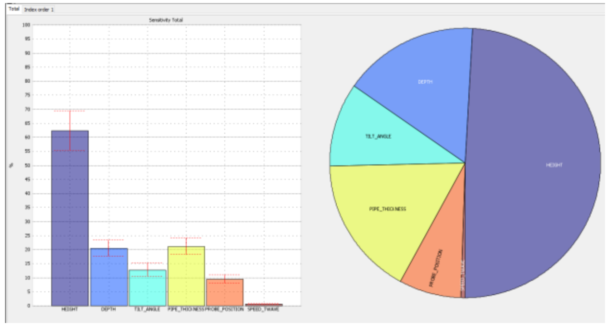
FILL1



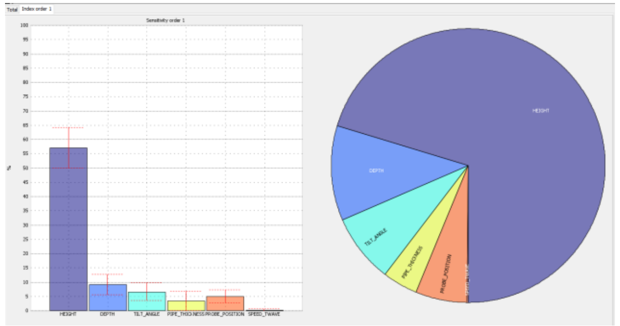


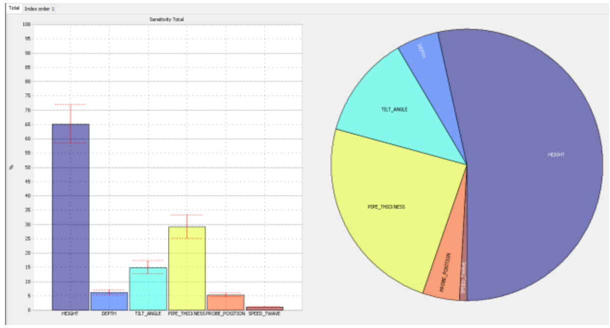
FILL3





FILL5





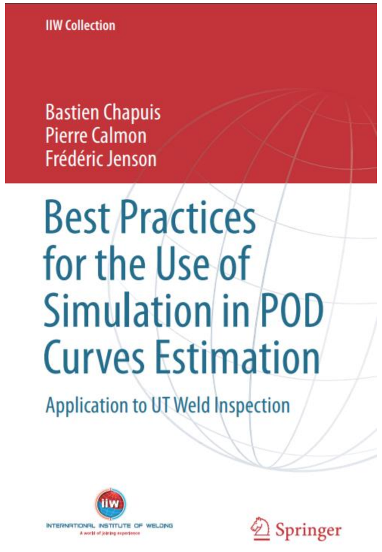
STEP4 : POD

- POD computations requires a large amount of data to be reliable => use of Metamodels

- POD must be applied globally (taking into account all channels and modes)

- Statistical aspects
  - Statistical drawing laws can be applied depending on the probabilities of the variability
    - to be defined for each variables (business expertise)

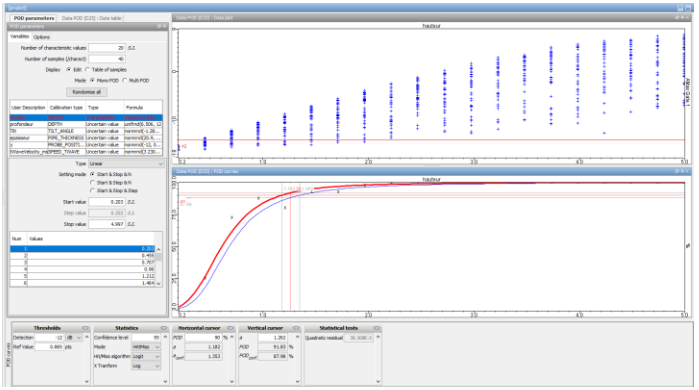
- Advantages of simulation :
  - Possibility to generate large amount of data
  - Possibility to explore configurations not accessible experimentally
  - Easier interpretation of results



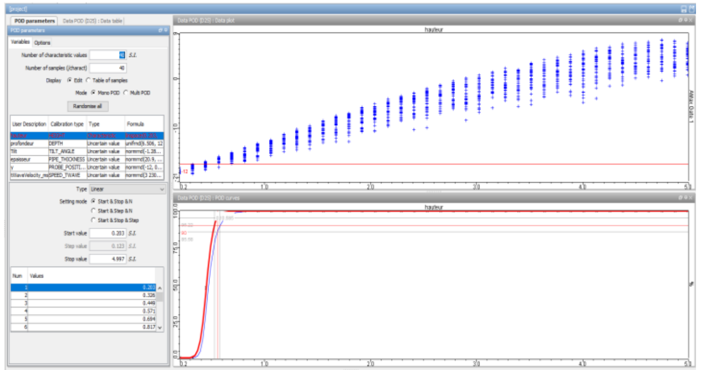
STEP4 : POD

Multi-channels POD : combining several channels of acquisition and integrating overlay of channels in the POD assessment (taking the maximum of amplitude among the channels involved)

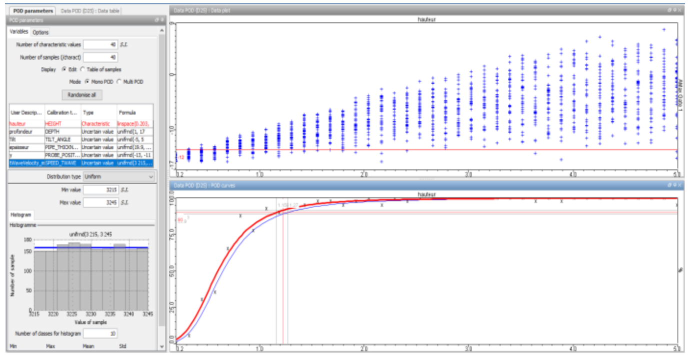
Fill 3 only / +/- 3mm depth
-12 dB
A = 1.2mm
Normal distribution



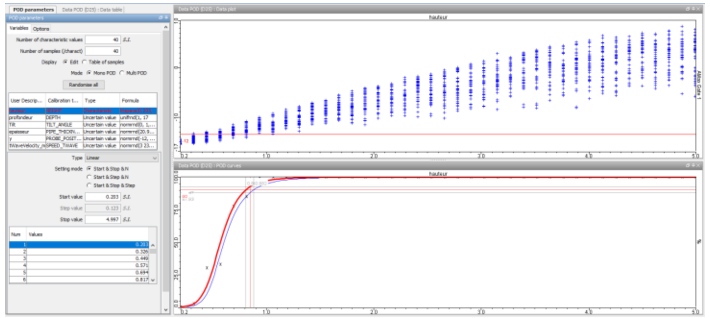
Fill 3 + Fill2 and Fill4 /
+/- 3mm depth
-12 dB
A = 0.56 mm
Normal distribution



POD for **All channels**
-12 dB
A = 1.22 mm
Uniform distribution



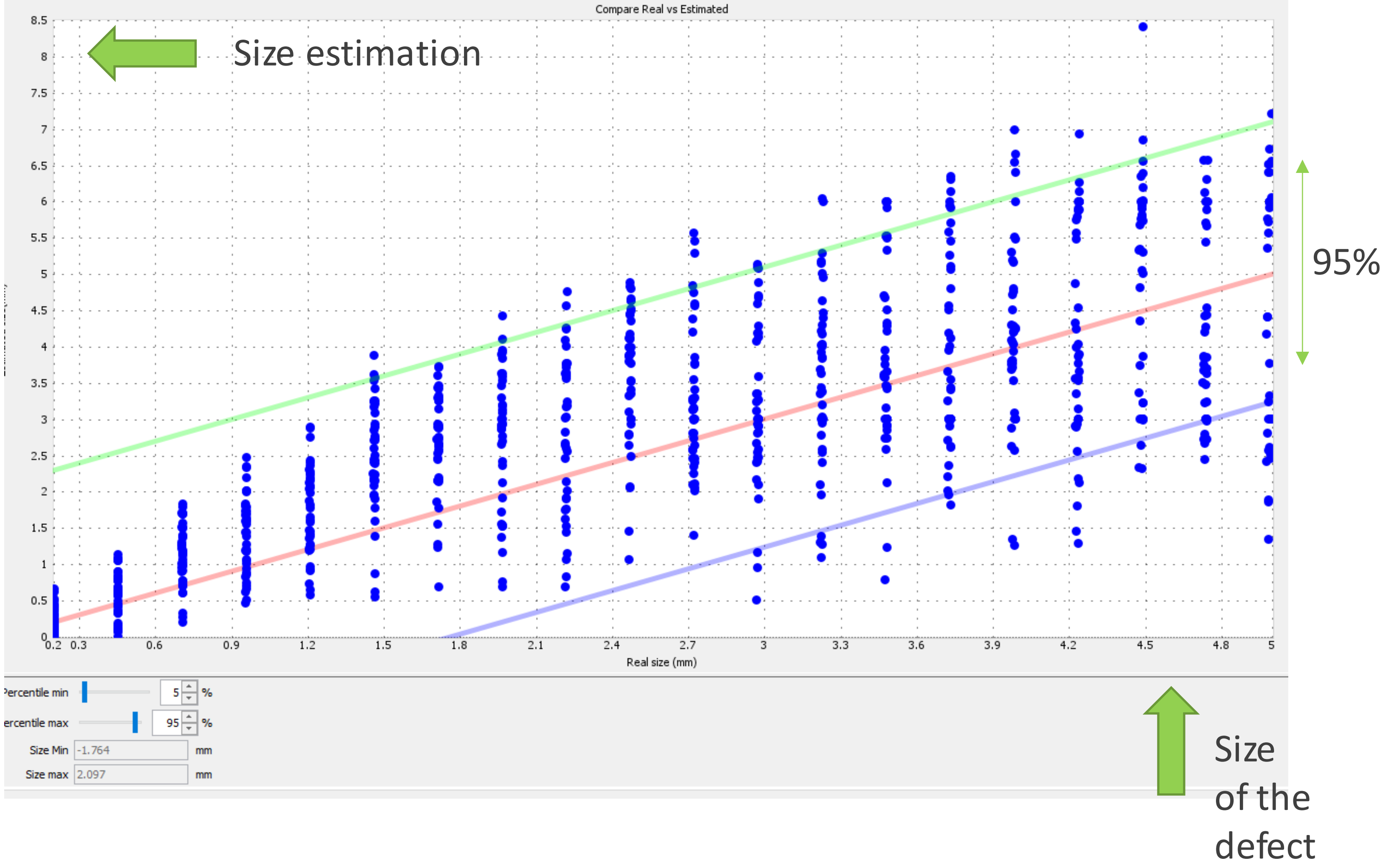
POD for **All channels**
-12 dB
A = 0.85 mm
Normal distribution



STEP5 : Sizing Accuracy

- Statistical studies for sizing accuracy require an automation of the sizing procedure
  - Automatic sizing procedure don’t have to reproduce the human procedure but must be based on equivalent criterions to be relevant

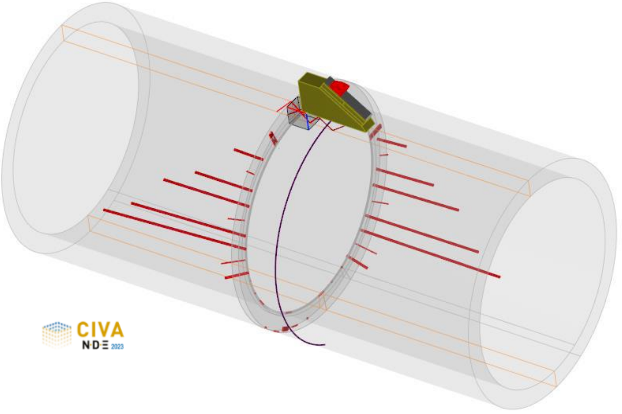
Results : Sizing error assessment (Sizing evaluation VS height of the defect)



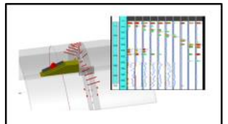
CIVA AUT PIPELINE : a specific module for AUT Pipe GW inspection

AUT Wizzards → AUT Calibration | AUT Sensitivity | AUT Sizing | AUT POD

Simulation for design and performance demonstration : **CIVA AUT PIPELINE**

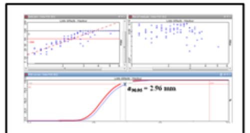


- Simple user access to the main inspection methods for AUT Pipe GW inspection
  - ZDM
  - TFM
- Specific GUI and workflow
  - Calibration :
    - Simple calibration block definition (reference defects, channels, probes, inspection settings, delay laws …)
    - Automation of the options and sequences of calculations
    - Analysis (Strip Chart, TFM multimodes …)
  - Sensitivity
    - Selection of essential variables
    - Building metamodels in the domain of variation
    - Impact for each variable, order 1 / order n (combination of variables), worst case / best case
  - POD (multichannels)
  - Sizing accuracy (error of sizing and sensitivity taking into account essential variables)
- Standard modules of CIVA (limited to Pipe GW configurations)

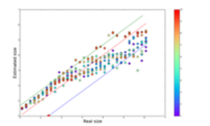


Calibration

Essential variables



POD



Sizing Accuracy

Demo available from EXTENDE booth #52

Simulation can be used at all step of the validation procedure of AUT Pipe GW Inspection

1- Calibration

2- Simulation strategy and Metamodels for statistical studies

3- Performance demonstration and essential variables

- Sensitivity Analysis
- POD
- Sizing accuracy

CIVA AUT Pipeline : a specific software for AUT Pipe GW inspections for an easy access to simulation
Soon compatible with CRA-CLAD configurations
TOFD developments in progress