SMART TUBULAR SOLUTIONS

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Démarche MAPoD appliquée à un banc de contrôle automatisé par ultrasons de tubes sans soudure

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Vallourec is a global leader in high-performance tubular solutions for the energy sector

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+12,000
employees

€3.8bn
of consolidated revenue (€819m EBITDA)

Over 135
years of history and expertise

€36m
spent on R&D

UNDISPUTED CUTTING-EDGE CAPABILITIES
in steelmaking, threading, rolling and heat treatment

1.244m tonnes
of tubes shipped

Figures as of December 31, 2025

We rely on 4 core businesses

HYDROCARBON Exploration & Production (including petrochemicals)

Tubes, connections, and services for **development of oil & gas fields, from the simplest to the most complex**

INDUSTRY

Lightweight and resistant tubes for **automotive, agribusiness, construction, mechanicals, etc.**

NEW ENERGIES

Tubes, connections and systems **for the hydrogen, geothermal and carbon capture markets**

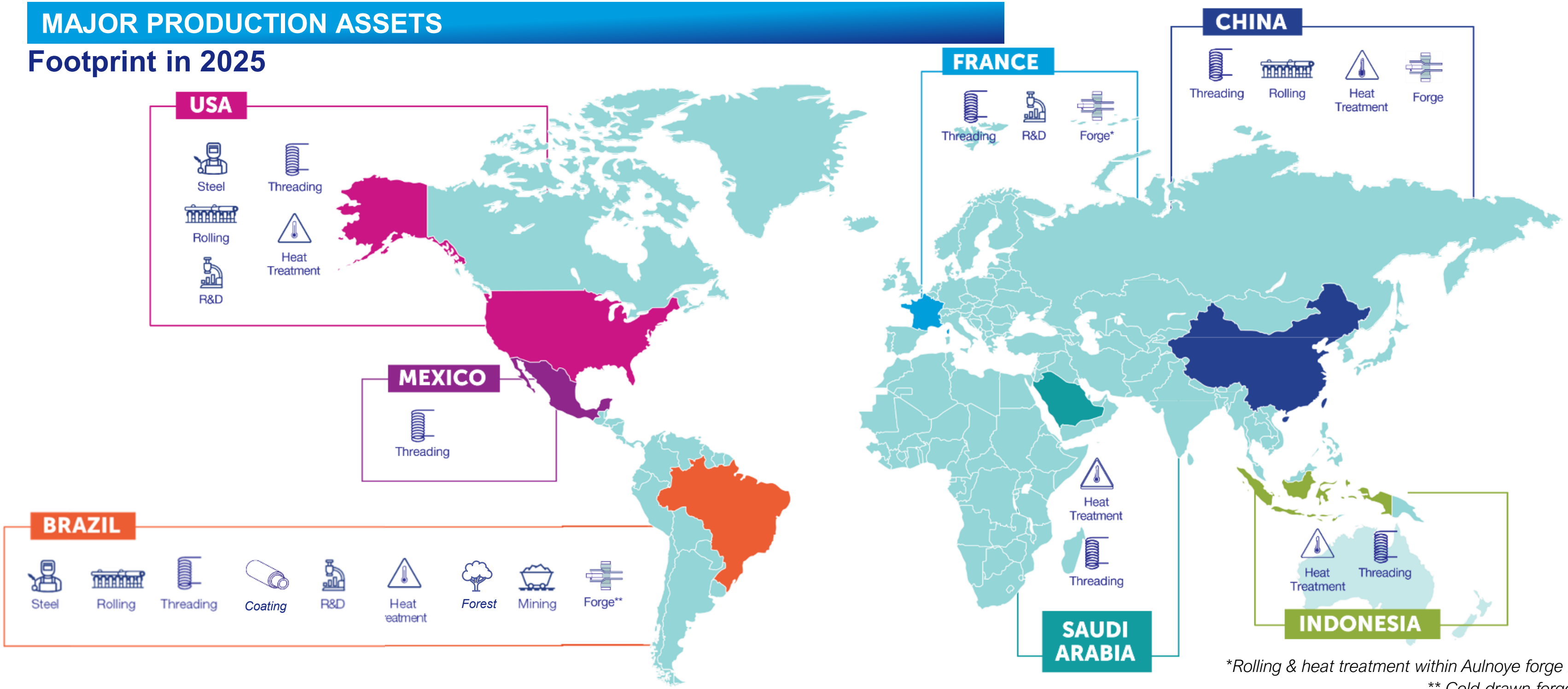
IRON ORE MINE

Operation of an iron ore mine in Brazil for external and internal use

Backed by an international presence

MAJOR PRODUCTION ASSETS

Footprint in 2025



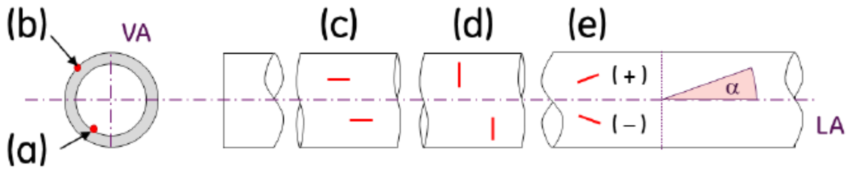
*Rolling & heat treatment within Aulnoye forge in France
** Cold-drawn forge in Brazil

Operating in **20+** **countries**	c.**36** **production sites**	**3** **major R&D centers** (Brazil, France, US)	**150** **VAM® licensees** worldwide

Figures as of December 31, 2025

Ultrasonic testing within Vallourec

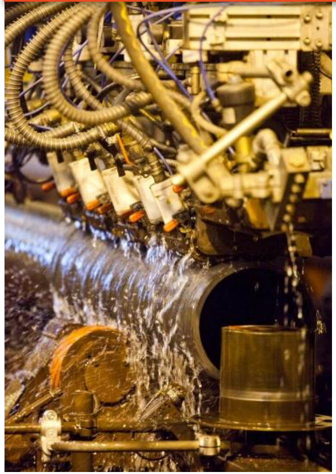
- ► Automatic UT benches are designed to detect **surface breaking defects** on seamless pipes



Definition referring to cross section	Definition referring to longitudinal axis:
(a) Internal flaw (IF)	(c) Longitudinal flaw (LF)
(b) External flaw (EF)	(d) Transverse flaw (TF)
	(e) Oblique flaw (OF)
	+ / – Rotation counter-/clockwise

UT benches use **phased array technology** with fixed angles, electronic beam steering, and linear scans, improving productivity and allowing detection of oblique flaws (paintbrush).

Automatic UT bench located in Brazil (VSB)



What is a PoD curve?

What is a PoD curve in NDT?

A **PoD curve** — Probability of Detection curve — is a **graphical tool** used in **Non-Destructive Testing** (NDT) to quantify how reliably an inspection system can detect flaws.

It answers a fundamental question: **for a given flaw size, what is the probability that my inspection method will detect it**?

What the curve shows?

1. **X-axis: Flaw size** - Typically the defect size “a” (depth or length).
2. **Y-axis: Probability of detection** - Values range from 0% to 100%
3. **Key metric: a90/95** - It means: 90% probability of detecting a flaw with 95% statistical confidence.

This is the industry standard—used widely in aerospace.

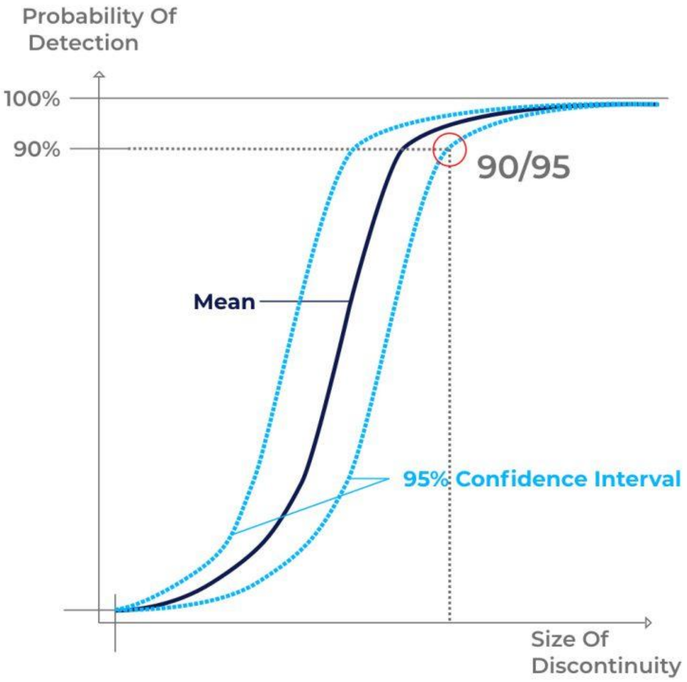
Why PoD curves matter?

A PoD curve provides a simple, intuitive summary of the detection capability of a NDT system.

It reveals limitations of the bench.

It supports decisions on:

- **optimizing inspection parameters**
- **upgrading equipment**
- **investment (CAPEX) justification >>> replacement**



Source: https://sentin.ai/en/what-is-the-probability-of-detection-pod-in-ndt/

How is a PoD computed within Vallourec?

Step 1 — Masterpipe manufacturing

Pipe extracted from production and cut

23 LOD notches

23 TOD notches

23 external oblique notches

Various notch lengths and depths

Step 2 — UT inspections on the bench

25 inspections on the masterpipe (end A to end B)

Pipe is flipped

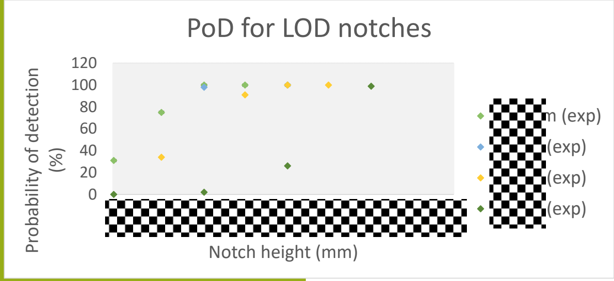
25 other inspections (end B to end A)

Step 3 — Full data analysis

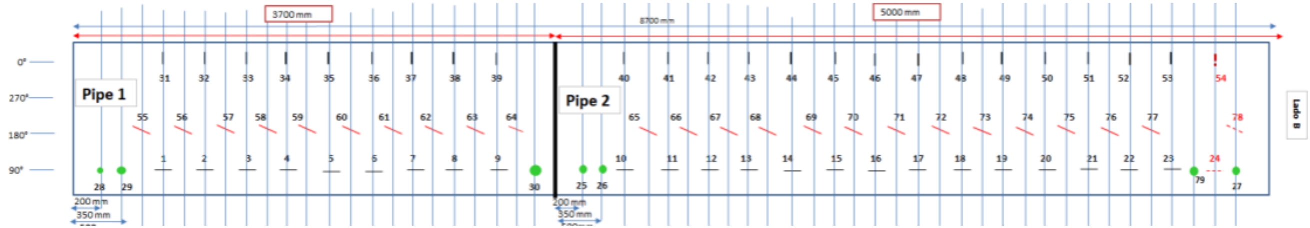
For LOD only = 23x25x4 = **2300 values** to manage

Standard production thresholds are then applied

Step 4 — Generation of PoD curves



Master Pipe name:	
Comprimento Tubo Padrão (mm)	8700
Diâmetro Ext (mm)	[redacted]
Parede (mm)	[redacted]



This methodology requires **numerous experimental trials** on pipes containing multiple artificial defects, making it particularly **costly**

What is a MAPoD curve?

What is a MAPoD?

MAPOD stands for Model-Assisted Probability of Detection. It is an evolution of classical PoD analysis that uses physics-based simulation models—rather than relying solely on experimental campaigns—to estimate the probability that an inspection system will detect a flaw.

Why MAPoD exists?

MAPoD provides a practical alternative:

- **Simulation models** approximate or replicate the physical behavior of the inspection process.
- **Statistical methods** use simulation output (sometimes combined with limited experimental data) to calculate PoD curves.
- The approach reduces the experimental burden while **maintaining reliability** of the results.

How is a MAPoD computed within Vallourec?

Step 1

Gather input data

Standard / nominal *configuration of UT bench*

1 configuration and 1 pipe dimension only

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Beam computations

Inspection simulations

Full system (all the virtual probes)

Step 3 Model simplification

Stay representative but must be faster for next steps

Step 4 Model validation

Generate simulation data to compare with available experimental data

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Identify the most influent ones on the final results

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Do a lot of simulations to allow smart interpolation by CIVA

Once the metamodel is created, computations are very fast

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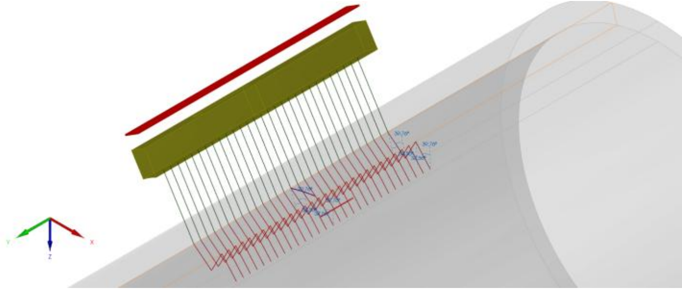
Step 7 Generation of PoD curves

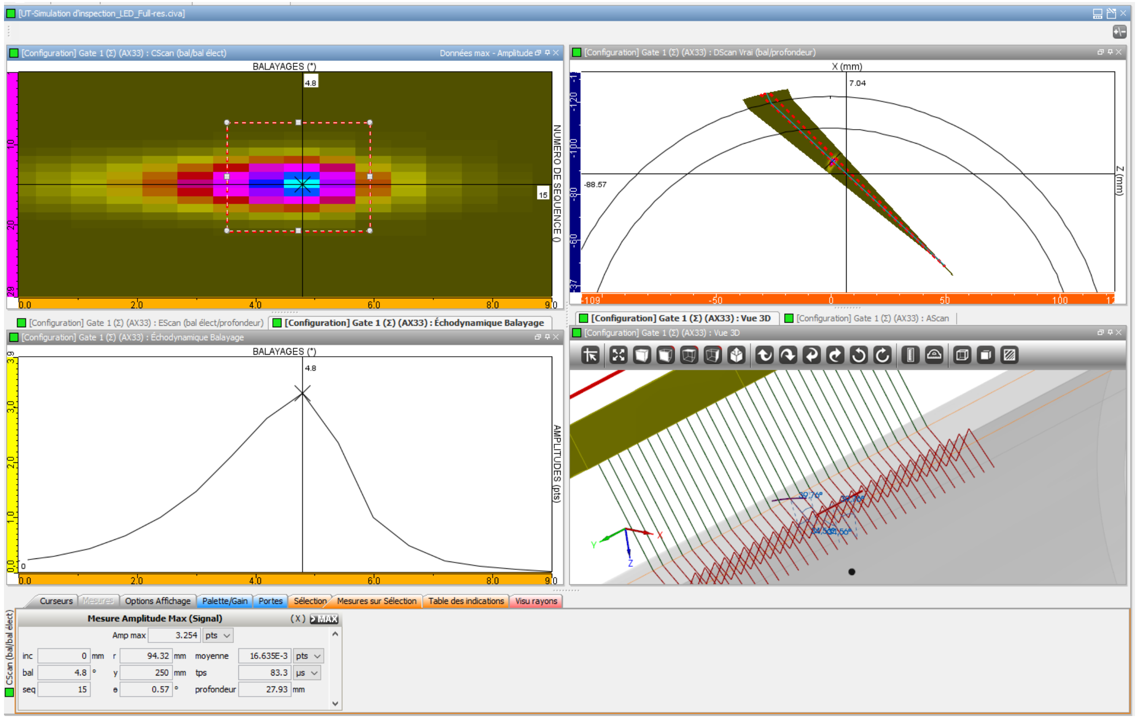
Check the metamodel quality first

Compute the required PoD curves

Step 2 – Inspection simulation – LED/LOD – Reference notch



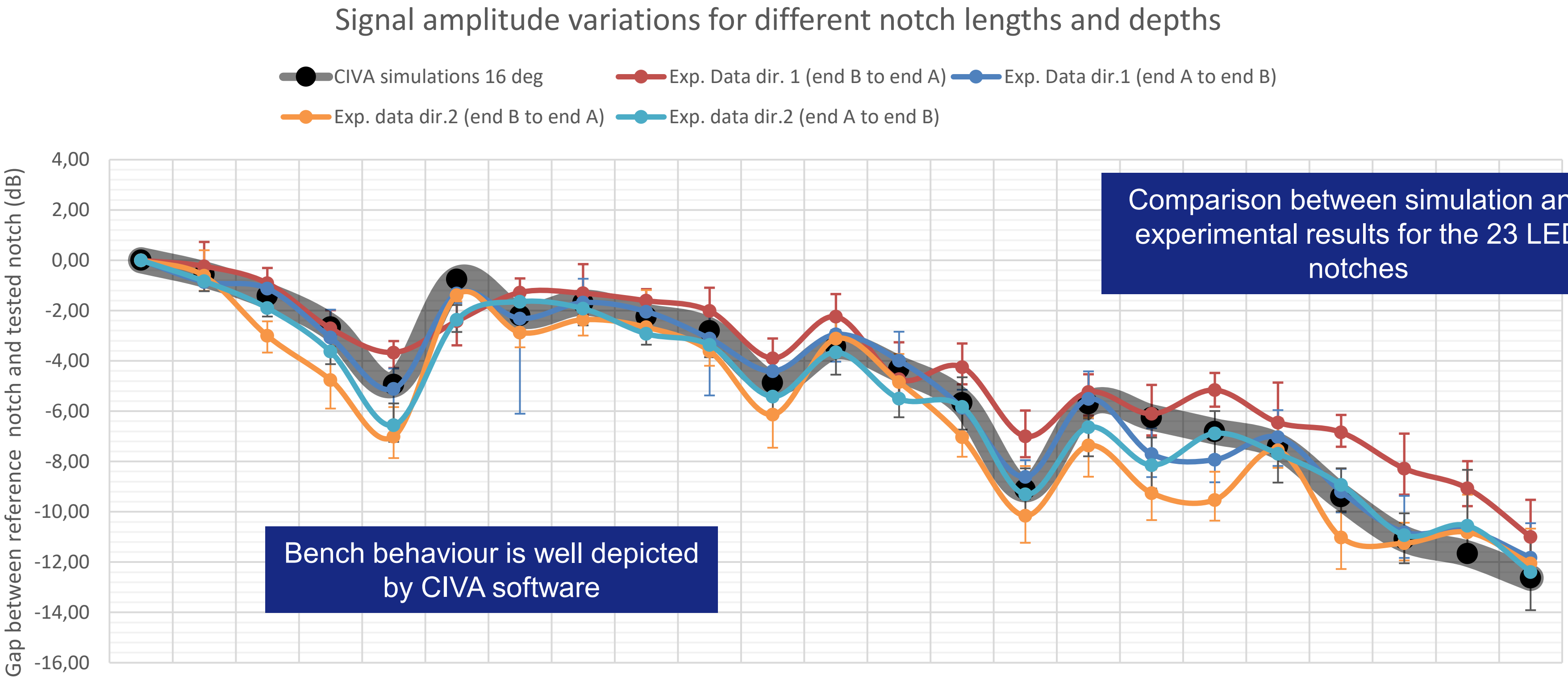
Full configuration
Linear PA probe with 256 elements, 2MHz
CAD file ("not a pipe")
Linear trajectory = 15 increments (15 * 0,6° = 9°)
K-GTD algorithm / Transverse wave
/ Full skip / 3D
Computation time = 22h



"LED = Longitudinal External Defects"

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Gather input data	First models	Model simplification	Model validation	Sensitivity analysis	Generation of metamodels	Generation of PoD curves

Step 4 – Results for LED/LOD



Comparison between simulation and experimental results for the 23 LED notches

Bench behaviour is well depicted by CIVA software

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Gather input data	First model	Model simplification	Model validation	Sensitivity analysis	Generation of metamodels	Generation of PoD curves

Step 5 – Sensitivity analysis

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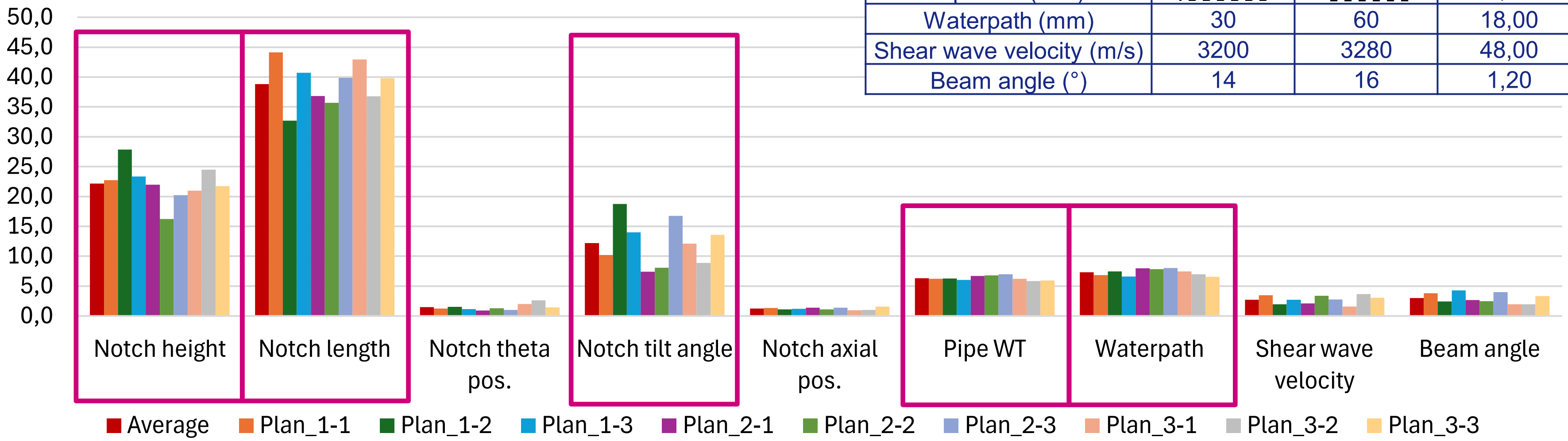
The Morris screening method is a one-at-a-time (OAT) perturbative sampling method for performing global sensitivity analysis (Morris, 1991)
Morris results are evaluated by comparing the mean of the absolute values of the elementary effects (EE) distributors for each parameter (μ*)

	Mini	Maxi	Variation (3/5)
Notch height (mm)	[redacted]	[redacted]	0,41
Notch length (mm)	[redacted]	[redacted]	12,24
Notch theta pos. (°)	-0,3	0,3	0,36
Notch tilt angle (°)	-30	30	36,00
Notch axial pos. (mm)	247,1	250	1,74
Pipe WT (mm)	[redacted]	[redacted]	2,08
Waterpath (mm)	30	60	18,00
Shear wave velocity (m/s)	3200	3280	48,00
Beam angle (°)	14	16	1,20

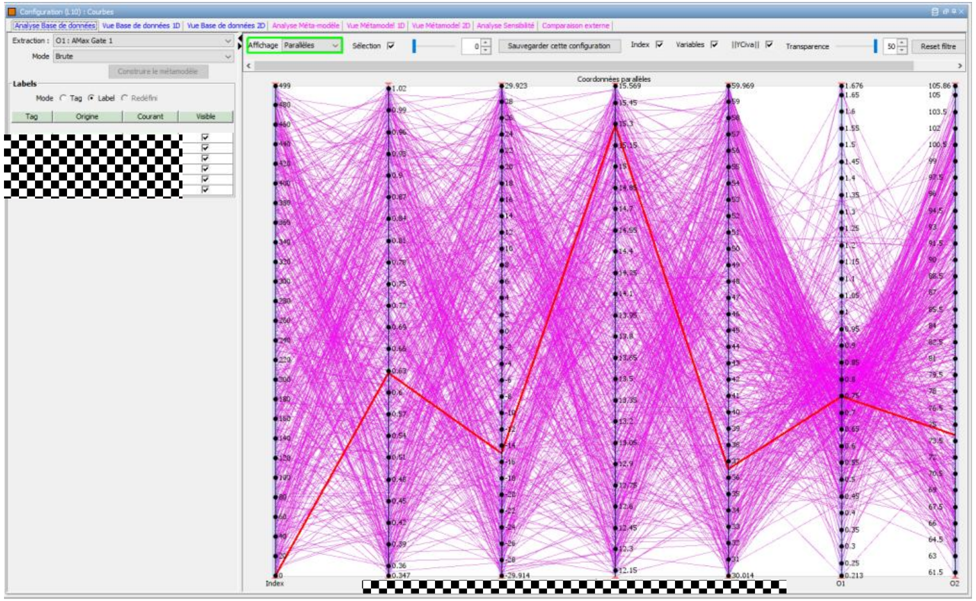
Impact of Morris designs on μ* [%]



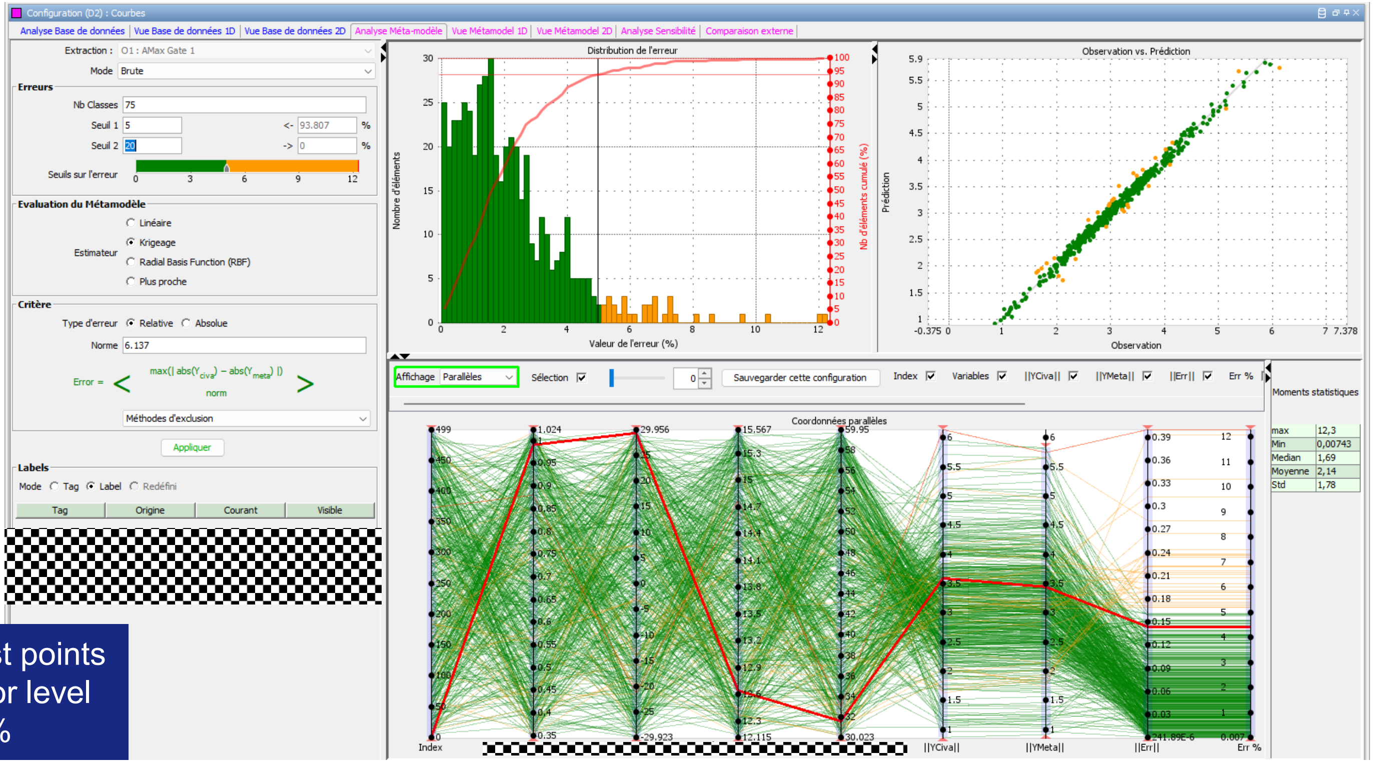
Step 1 Gather input data | Step 2 First model | Step 3 Model simplification | Step 4 Model validation | Step 5 Sensitivity analysis | Step 6 Generation of metamodels | Step 7 Generation of PoD curves

Step 6 – Metamodel definition

- 6 metamodels were generated with CIVA, one for each of the following notch lengths.
- Varying parameters were the following ones:
  - Notch height = XXXmm to XXXmm
  - Tilt angle = -30° to 30°
  - Pipe WT = XXXmm to XXXmm
  - Waterpath = 30mm to 60mm
- 500 simulations
- Full random parameter sets



Step 6 – Metamodel behaviour



93,8% of test points with an error level <= 5%

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Gather input data	First model	Model simplification	Model validation	Sensitivity analysis	Generation of metamodels	Generation of PoD curves

Step 7 – CIVA module dedicated to PoD

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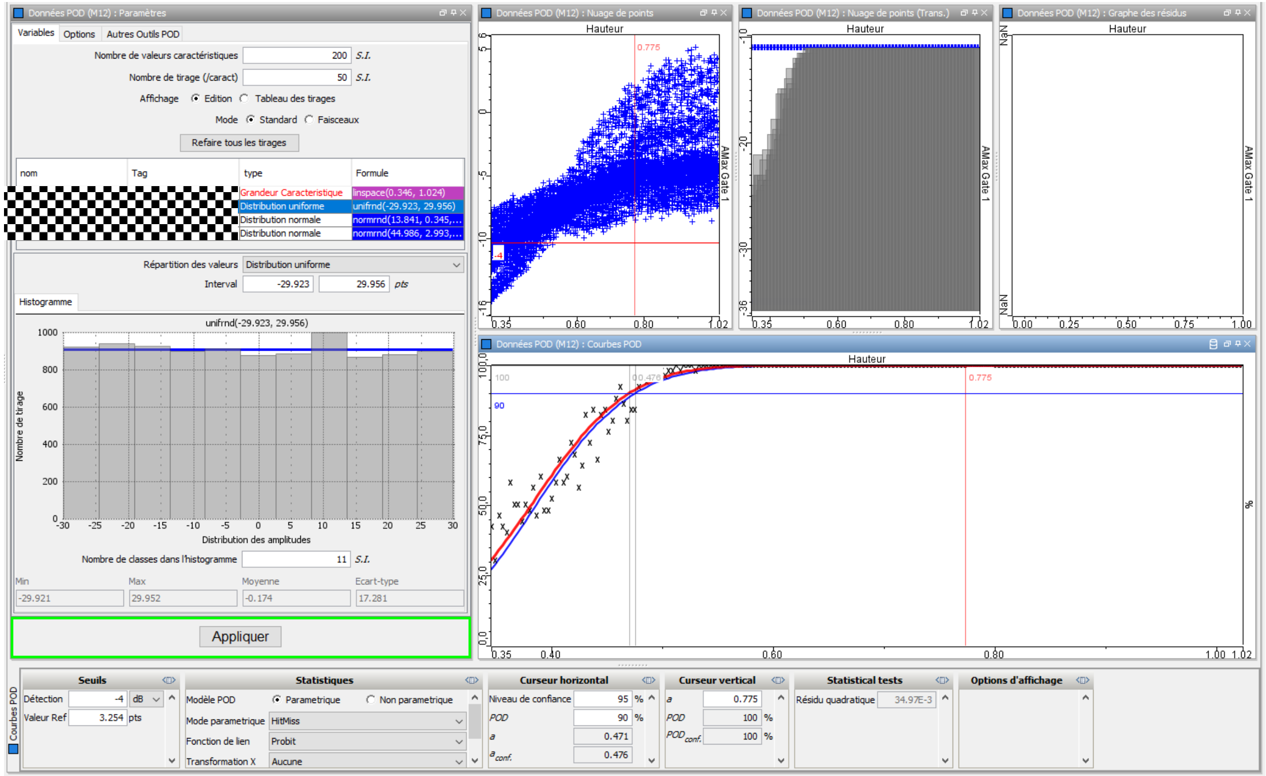


Step 1 **Gather input data**

Step 2 **First model**

Step 3 **Model simplification**

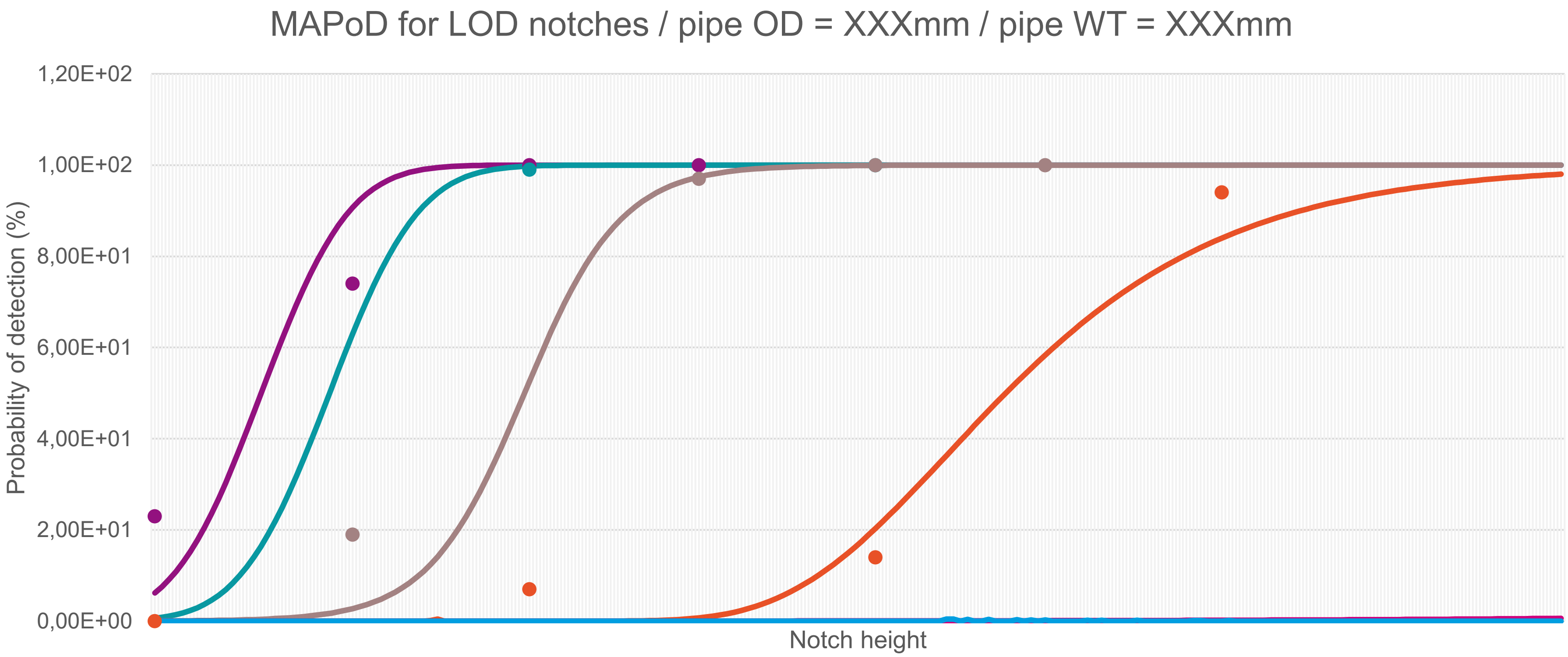
Step 4 **Model validation**

Step 5 **Sensitivity analysis**

Step 6 **Generation of metamodels**

Step 7 **Generation of PoD curves**

Step 7 – Some results for LED/LOD



Step 1 **Gather input data**

Step 2 **First model**

Step 3 **Model simplification**

Step 4 **Model validation**

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Step 6 **Generation of metamodels**

Step 7 **Generation of PoD curves**

CONCLUSION & PROSPECTS

First trials using **MAPoD** methodology (real bench, LED/LOD only)

- **Good feedback** on the use of CIVA and on the "**NDT reliability**" training delivered by Extende
  - Ease of use (available tools)
  - Simulation results VS experimental results >>> good correlation
- **Relevant results** VS experimental PoD

Benefits of MAPoD VS PoD

- **Reduced number** of experimental trials (bench availability, costs)
  - From 23 notches to 3 notches (we still need to validate the CIVA simulation results)
- **Extended possibilities**
  - LID, TID and FBH for example (difficult to manufacture)
  - Other pipe dimensions
- Better understanding of the impact of influencing parameters
- Use of **metamodels**
  - Easy and fast access to infinite number of PoD curves
  - Possibility to define new bench settings and to test them (quality)

Finalize the study on the first UT bench

- Study TED/TOD
- Study LID and TID
- Methodology to be **standardized**

Thank you for your attention !

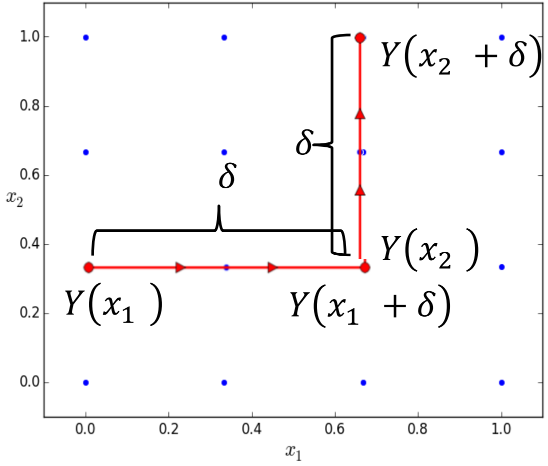
https://youtu.be/W4PGmTY3MSg?si=3XL7wj5XRT7Sx0ll

Méthode de Morris

► Principe de la méthode:

1. Création d'un **plan d'expériences *un-à-la-fois*** :
   - » 1ère expérience en fixant une valeur à chaque variable
   - » Perturbation δ de chaque variable **l'une après l'autre** avec un pas de perturbation fixe
2. Calcul de l'effet induit par chaque perturbation de chaque paramètre sur la donnée de sortie
3. Répétition de l'opération en partant d'un autre état nominal des différentes variables, autant de fois que le nombre de trajectoires choisies et analyse des effets induits par chacun des paramètres pour l'ensemble des trajectoires (impact moyen, etc.)

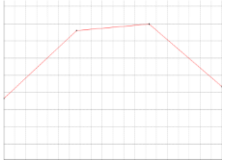
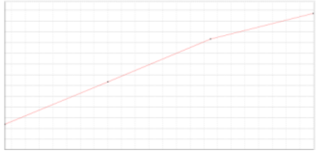
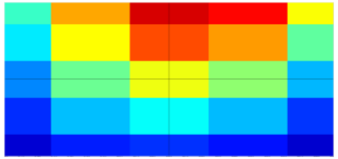
Exemple d'une trajectoire pour 2 variables:



Métamodèle

► Un métamodèle en quelques mots :

- A partir d’une grille discrète de résultats obtenue en faisant varier des paramètres d’entrées (simulations, calculs ou mesures) :

- Application d’algorithmes d’**interpolation** « intelligents » pour construire (à partir des points « connus ») un modèle mathématique continu sur l’espace de variation de l’ensemble des paramètres variables.