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Evolution de la simulation du monitoring et du contrôle dans la plateforme logicielle CIVA

Edouard Demaldent

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Edouard Demaldent. Evolution de la simulation du monitoring et du contrôle dans la plateforme logicielle CIVA. Séminaire du Club des affiliés du LMPS 2023, Laboratoire de Mécanique Paris-Saclay; ENS Paris Saclay; Université Paris-Saclay; CentraleSupélec; CNRS, Nov 2023, Palaiseau, France. cea-04902500

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Submitted on 21 Jan 2025

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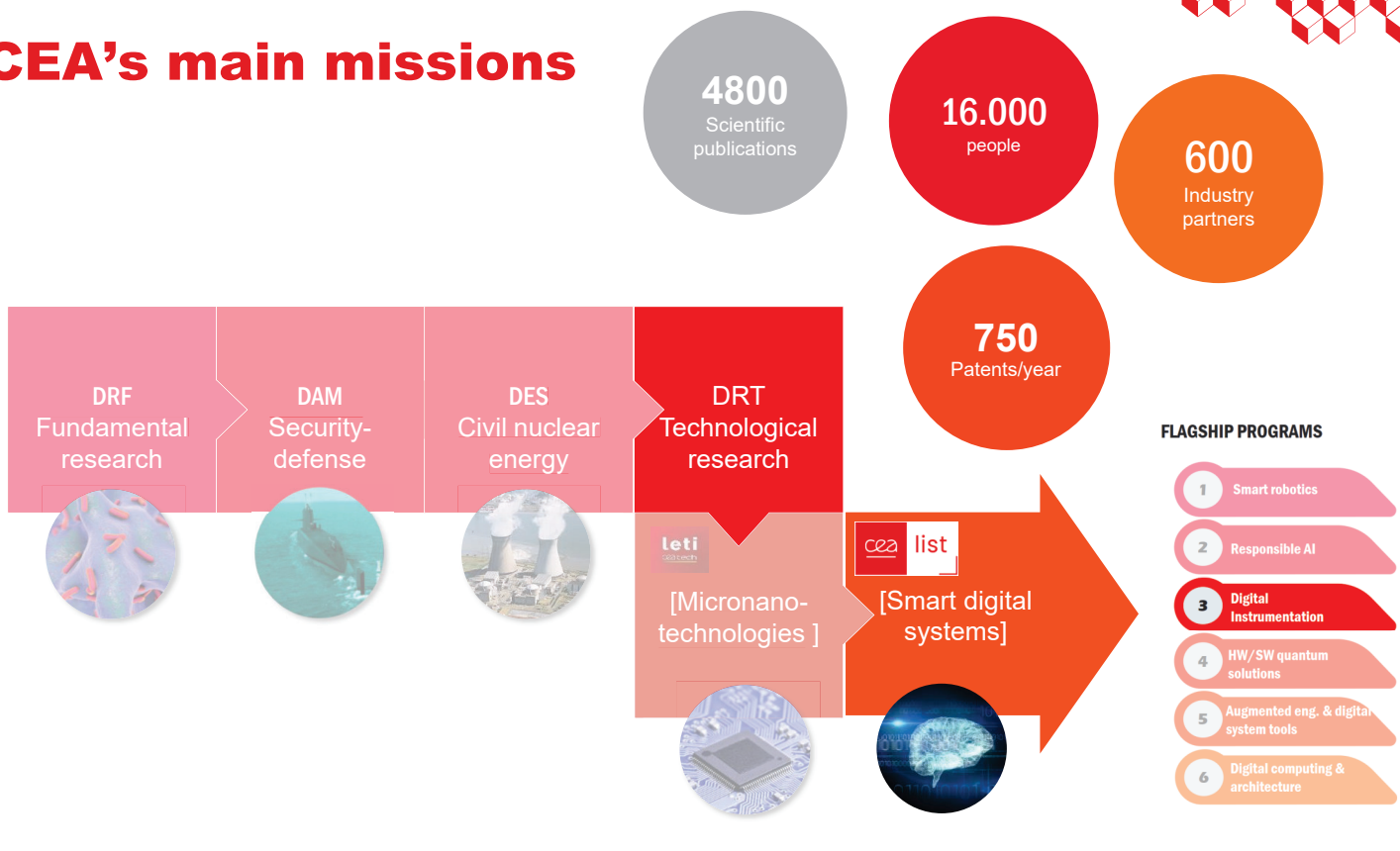


Evolution de la simulation du monitoring et du contrôle dans la plateforme logicielle CIVA

Edouard DEMALDENT
Laboratoire de Simulation, Modélisation et Analyse
Université Paris-Saclay, CEA, List, F-91120, Palaiseau, France



CEA's main missions





Non destructive evaluation at CEA List

01

- NDE team at CEA List : ~ 110 staff members including 25 PhD & post-doc
- Large industrial partnership in main sectors concerned by NDE
- Strong academic collaborations : through CIVA network, National, European and International projects, ...



02

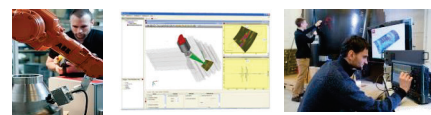
- Three-fold R&D activity



Addressing the main NDE modalities:
Ultrasound, Electromag. (ET,...), X-Ray & CT, Guided Waves,
Thermography (IR), ...

03

- Experimental & numerical platforms





SACHEMS

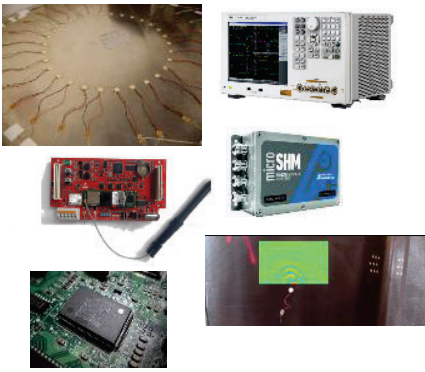
SAClay High-end Equipment for the Monitoring of Structures

Co-funded by the region « Ile de France » and industrial partners 

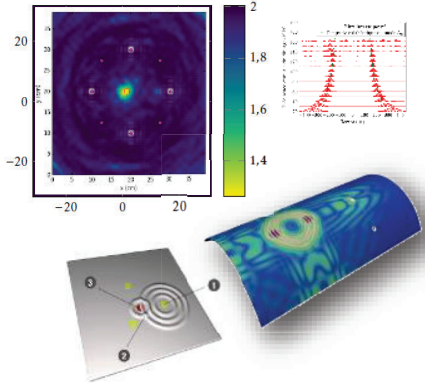


- Development and assessment of technologies (sensors, algorithms, software)
- Integration in SHM prototype systems
- Assessment and performances demonstration on industrial mock-ups

Instrumentation for SHM



Imaging and data processing





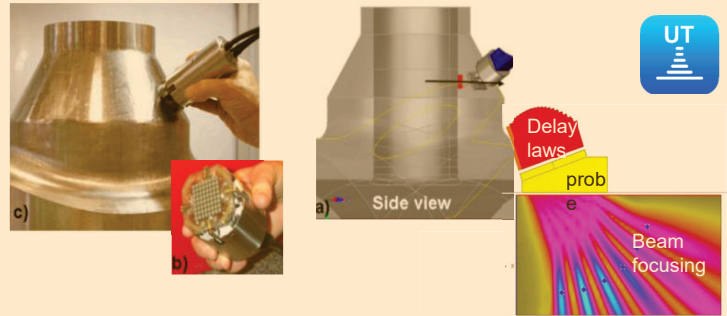
A true (enough) CIVA story



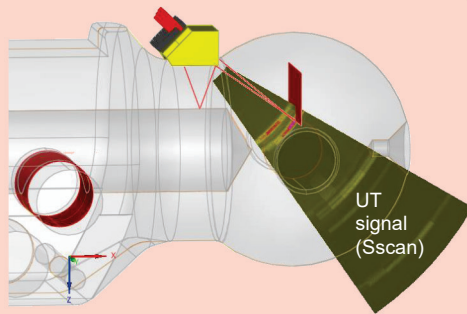
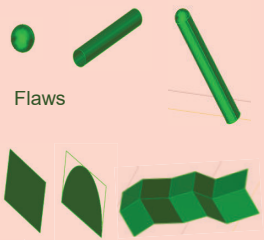
Semi-analytical & hybrid modelling

Ray tracing algorithm (time of flight)
or paraxial (beam calculation)

→ Support for signal interpretation
(modal analysis), emergence of multi-
element sensors



Flaws

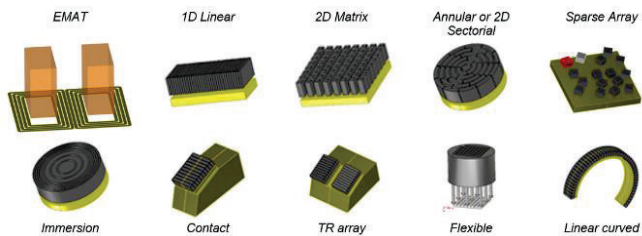


Hybridization with SA (Kirchhoff, KGTD,
SOV...) or FEM flaw response models,
Auld reciprocity

→ Full inspection simulation,
performance demonstration...



An easy access to advanced modelling

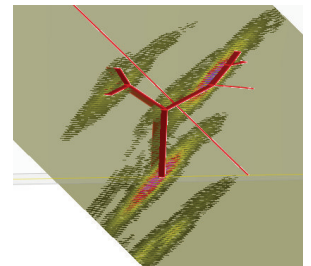
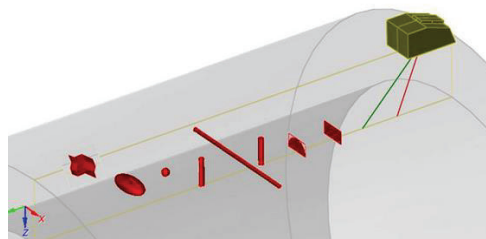
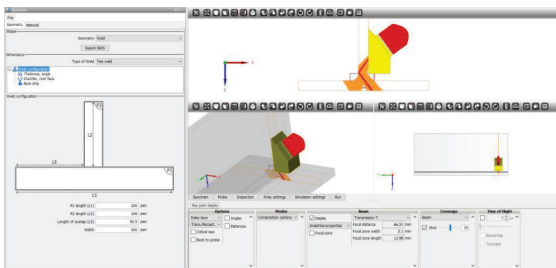


Probes and Materials Data Base
Parametric and CAD specimens
Parametric and robotic trajectories
3D Visualization, User-friendly

Standard PC compatibility



Simple case: less than a minute
Complex case: less than an hour
Very complex case: less than a day



Parametric studies and statistical approaches



Geometry Rectangular

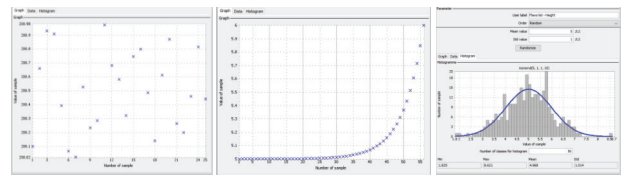
Length 20 mm

Height 5 mm

VAR: Add to variation

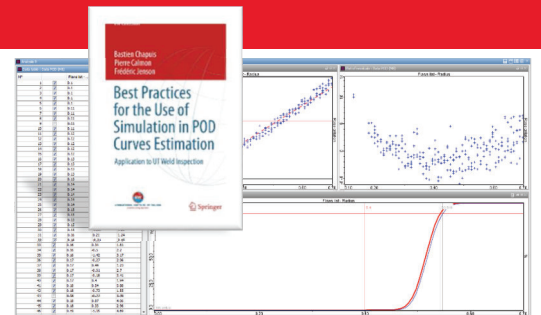
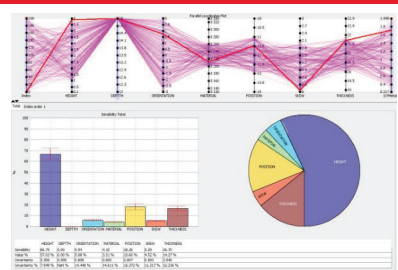
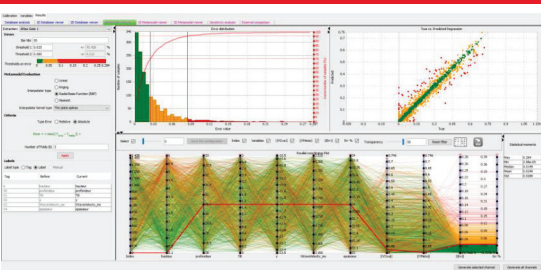
VAR: Add to parameter monitored

Nr...	Category	Tag	Type	Min	Max	Size	Curren...	Dim
1	Characteristic	LENGTH	Linear spacing	20	215	20		
2	Characteristic	HEIGHT	Linear spacing	5	65	5		
3	Variable	LPS		200	201.05	200		
4	Variable	DISORIENTATION	LPS	0	1	0		



- Parametric variations
- Metamodeling
- Sensitivity studies
- POD

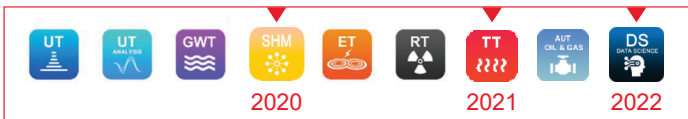
Any parameter can be considered as a "variable"



NDE simulation software platform



A multi-technique software platform



CIVA NDE-I

Developed by CEA-List
Distributed by EXTENDE

WORLD LEADER IN NDT SIMULATION

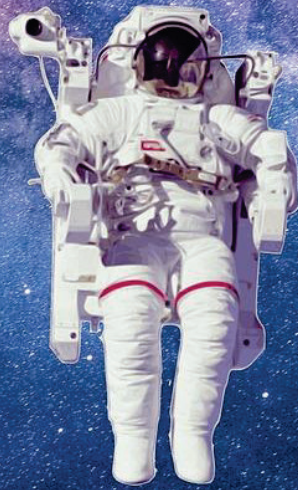
CIVA USERS: More than **300 companies**
and Labs in **40 countries**

NDE Simulation and analysis

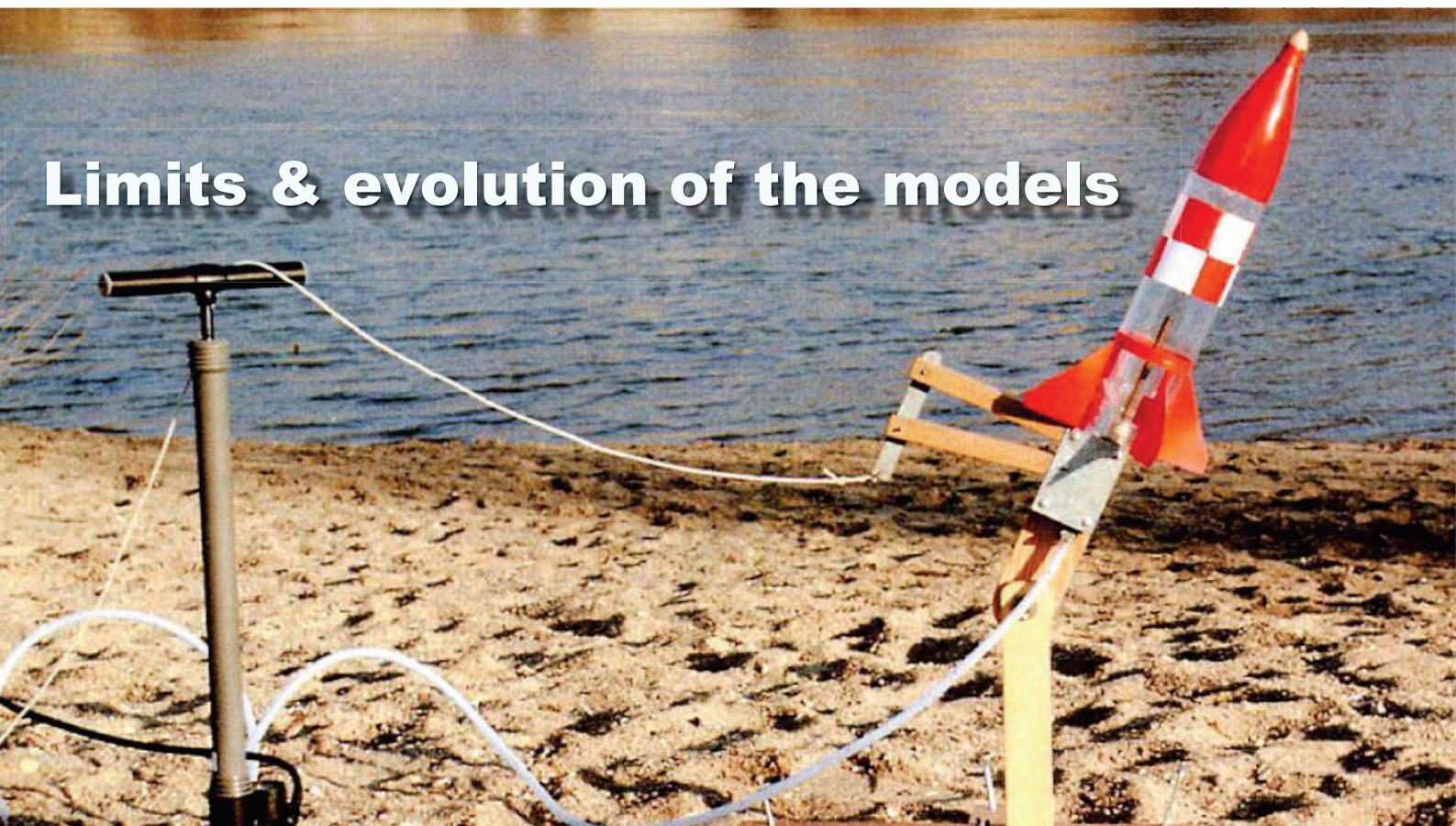
- Scientific strategy: To integrate within the platform the results of basic research (internal or collaborative) achieved at CEA List.
- Release of annual versions containing new tools based on this research
- CIVA is also a collaborative plat-form: Integration of modules developed by partners, Plug-In technology, dedicated tools for specific applications



CIVA 4 AI



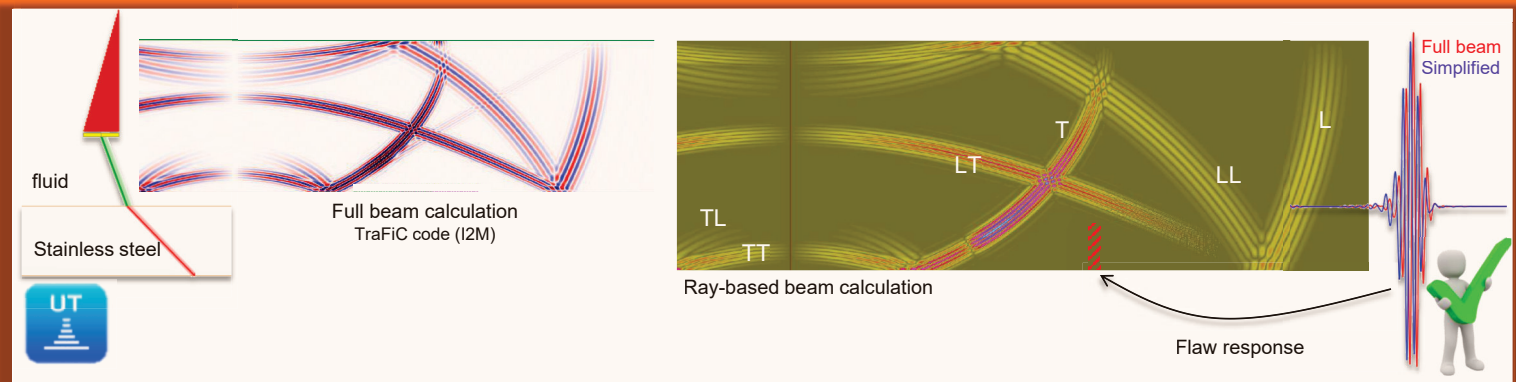
Limits & evolution of the models





Known (and obvious) limits

Known (and obvious) limits...



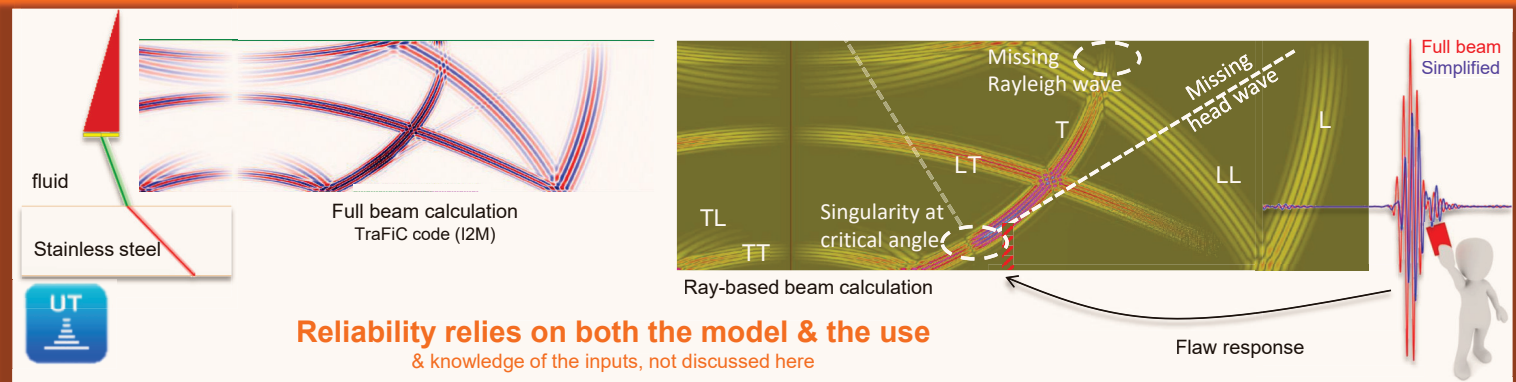
Known (and obvious) limits...



The diagram compares two modeling approaches for an ultrasonic beam at a fluid-to-stainless steel interface. On the left, a 'Full beam calculation' using 'TraFiC code (I2M)' shows a complex, multi-colored wave pattern. On the right, a 'Ray-based beam calculation' shows a simplified wave pattern with labels for 'TL', 'TT', 'LT', 'T', 'LL', and 'L'. It highlights a 'Singularity at critical angle' and 'Missing' waves: 'Missing Rayleigh wave' and 'Missing head wave'. A 'Flaw response' graph on the right shows a sharp peak, with a 3D figure holding a green checkmark. A 'Full beam Simplified' label is also present.

Be aware of the model limits
most often ok for toy-problems but hardly difficult for industrial needs

Known (and obvious) limits...



A phenomenon exacerbated by the advent of parametric studies and automatic analysis tools

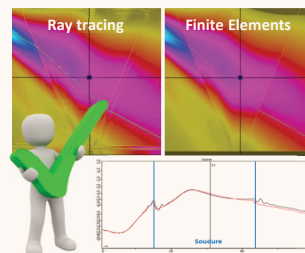
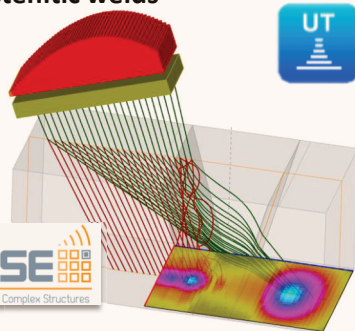
...quickly become hard-to-predict problems



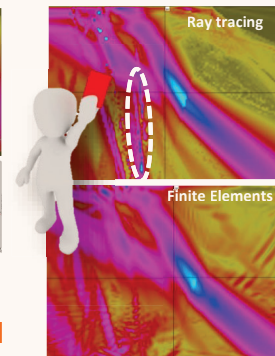
The ultrasonic testing of austenitic welds Complex structured materials



ADVISE
Advanced Inspection of Complex Structures



At some point, prior cross-simulation evaluation is needed



while simulation remains (reasonably) idealized: probe coupling, chamfer geom., material prop...



Gradual introduction of FEM

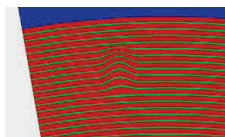
Motivations

- Qualify standard CIVA models / Supplement them in critical cases
- Compatible with a standard PC: NDT studies in 2D, a few shots or scans in 3D

Early 2010s: Athena (edf), Fidel (airbus, FDTD) – 2D only

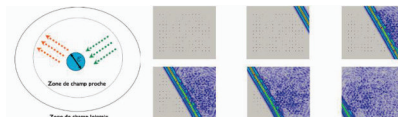


R&D at CEA with



Postdoc **Edouard Demaldent**
Simulation of the ultrasonic testing of a stratified composite medium with fold undulation

Proof of concept

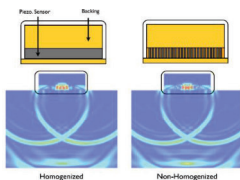


PhD. **Simon Marmorat**
Asymptotic models and numerical simulation for the diffraction of waves by small defects

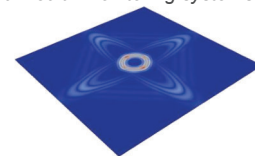
First apparition in a CIVA release (small defect)



PhD. **Sébastien Imperiale**
Mathematical & numerical modeling of piezoelectric transducers



PhD. **Hajer Metheni**
Domain decomposition approach for the simulation of ultrasound structural health monitoring systems

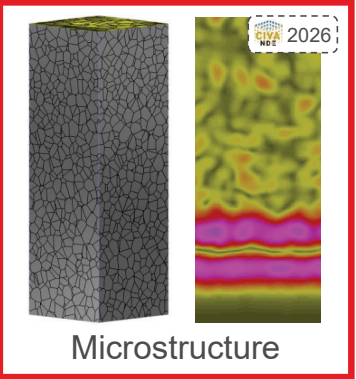
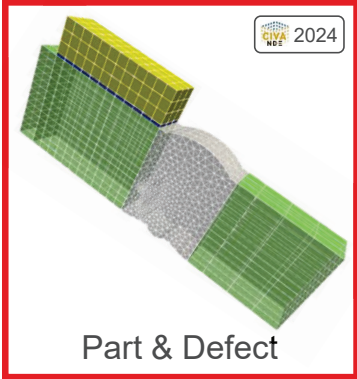
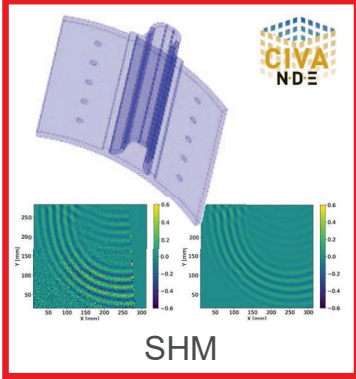
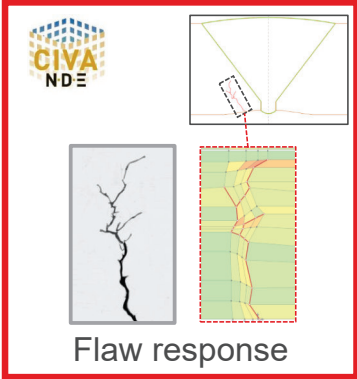


Alexandre Imperiale
Permanent job position at CEA LIST
Re-mastering of the SFEM code

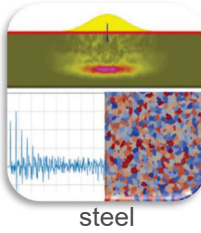
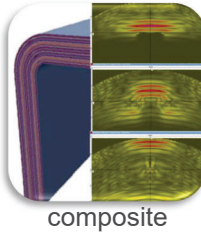
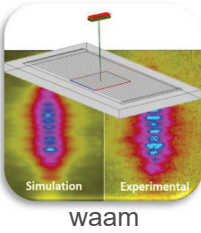


R&D at CEA within CIVA

- Gradual introduction of transient FEM and hybrid tools in CIVA UT



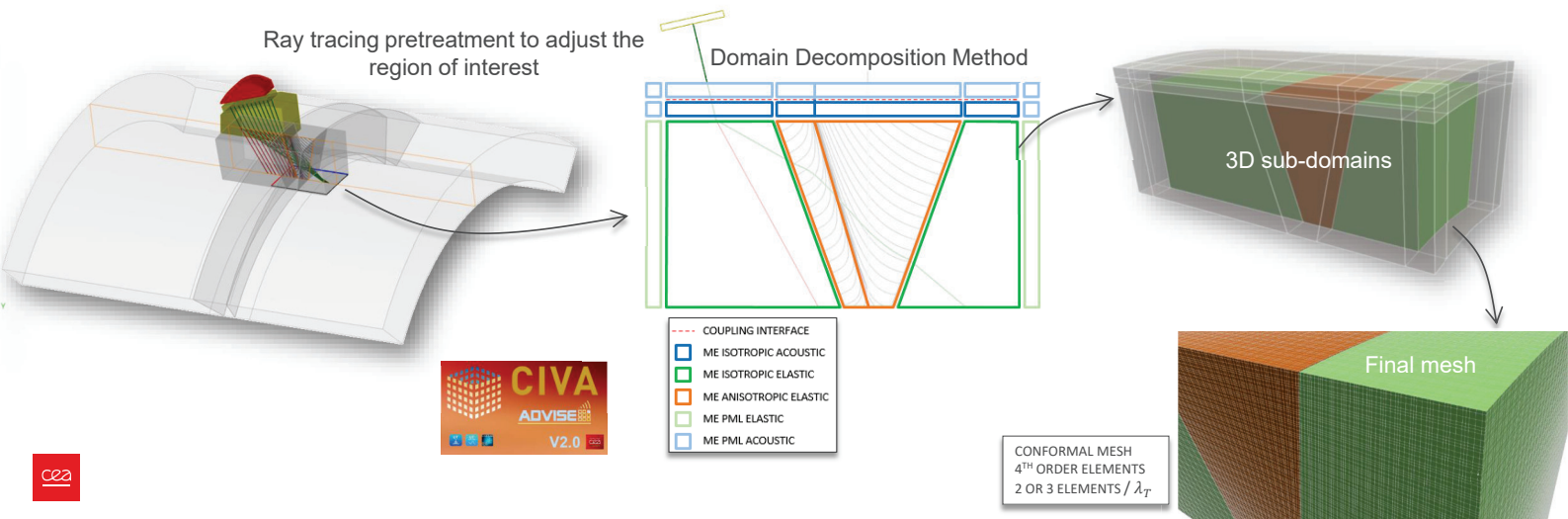
- Customized CIVA-UT module for some NDT studies





Transient FEM model

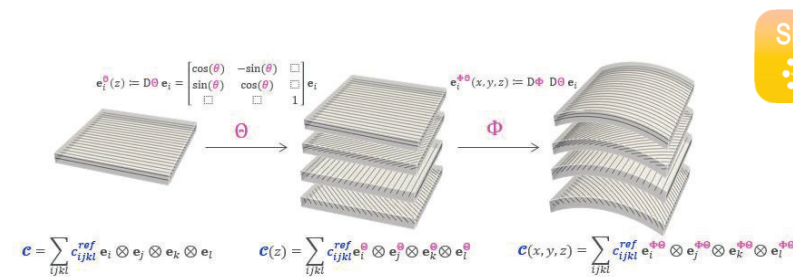
- Spectral-like transient FEM → High-order hexahedrons, time-explicit, factorized stiffness mat-vect, low memory footprint...
- Mortar DDM for stability and ease of coupling of propagators → fluid, solid, visco, PML, ETC...
- Hyper-mesh description of the inspection scene





Hyper-mesh description

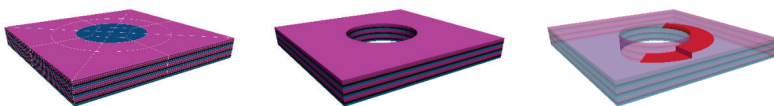
- Parametric configuration description with pre-meshed patterns
- A closed notch/delamination is assimilated to a deactivated mortar interface



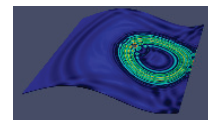
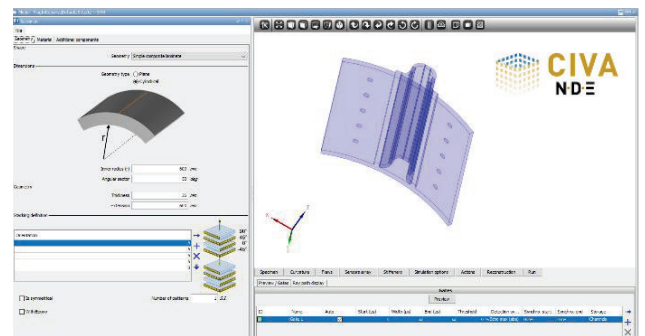
$$c = \sum_{ijkl} c_{ijkl}^{ref} e_i \otimes e_j \otimes e_k \otimes e_l$$

$$c(z) = \sum_{ijkl} c_{ijkl}^{ref} e_i^{\theta} \otimes e_j^{\theta} \otimes e_k^{\theta} \otimes e_l^{\theta}$$

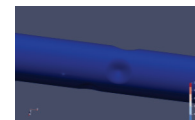
$$c(x,y,z) = \sum_{ijkl} c_{ijkl}^{ref} e_i^{*\theta} \otimes e_j^{*\theta} \otimes e_k^{*\theta} \otimes e_l^{*\theta}$$



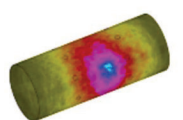
Considered defects are parametric and have their own meshing pattern



Wave propagation

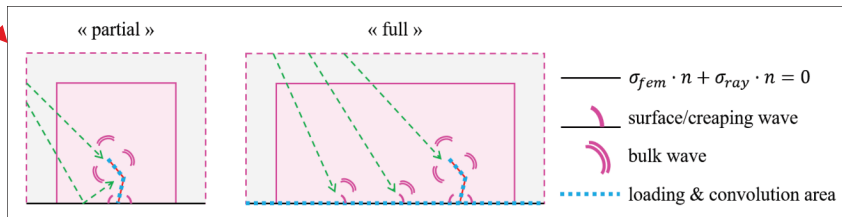
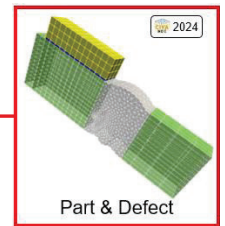
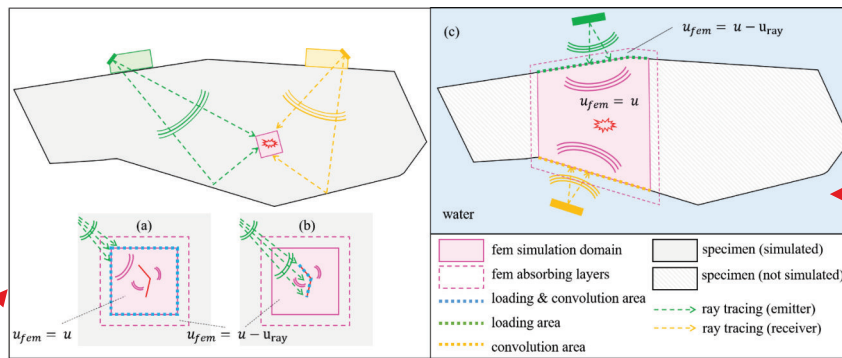
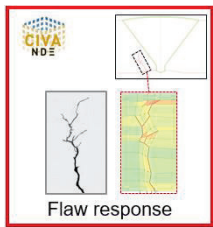


Guided wave imaging in a pipe



Hybridization strategies

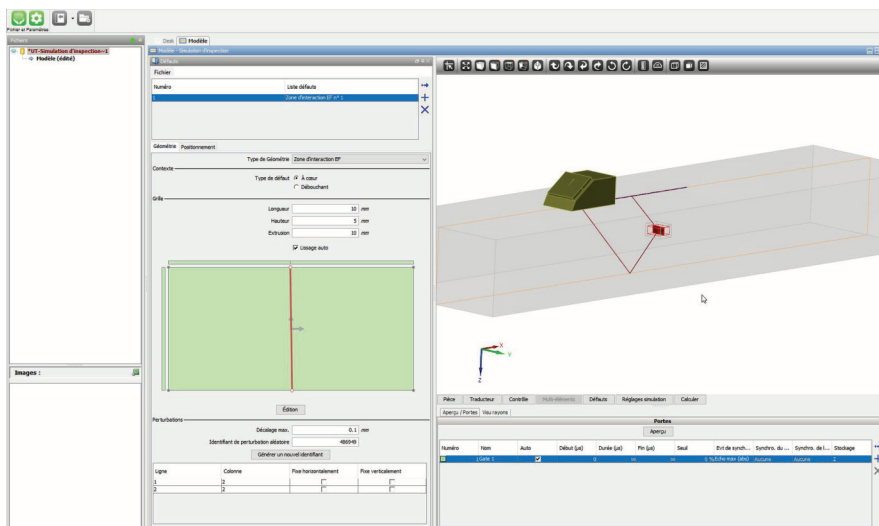
- Trade off between performance & accuracy & accessibility



Custom GUI tools



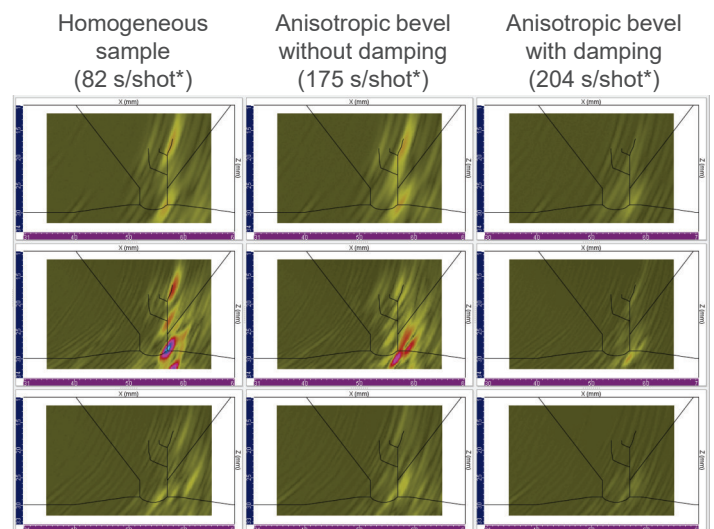
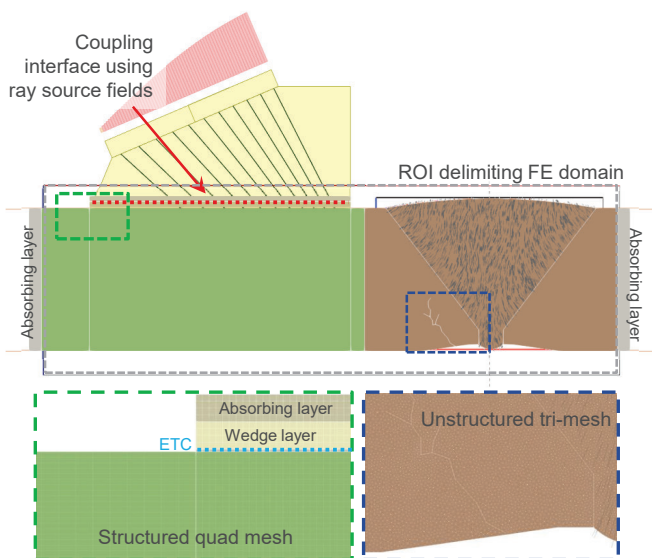
- Trade off between performance & accuracy & accessibility (again)





Extension to CAD 2D & 2D5

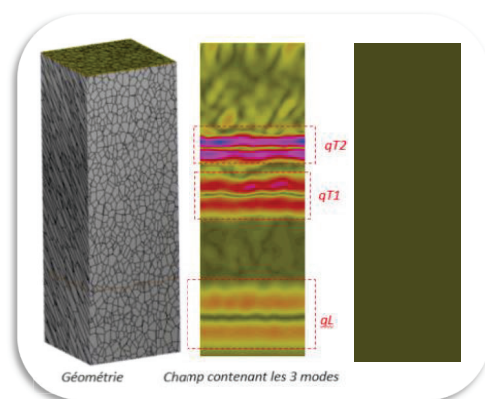
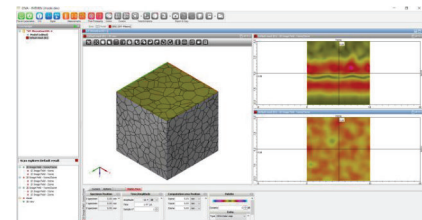
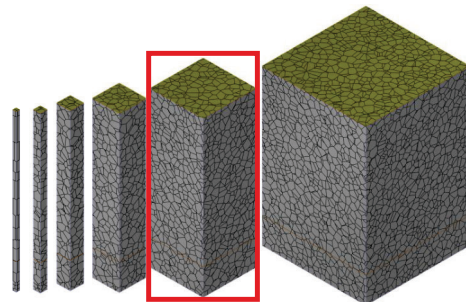
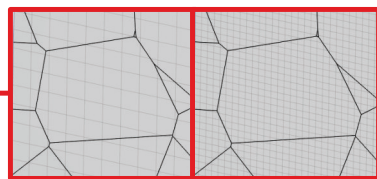
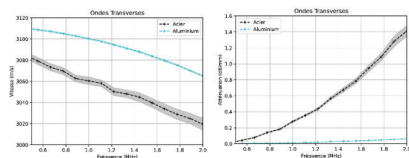
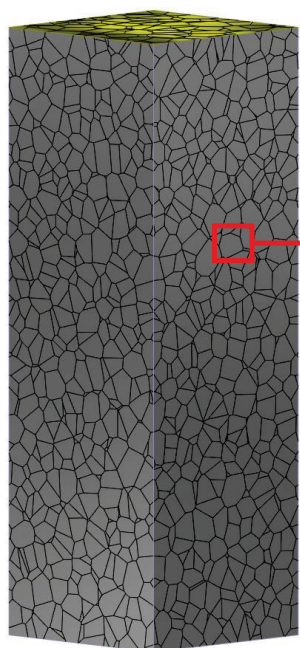
- Trade off between performance & accuracy & accessibility (and again)





Periodic FEM grid for microstructures

- Trade off between performance & accuracy & accessibility (and again !)

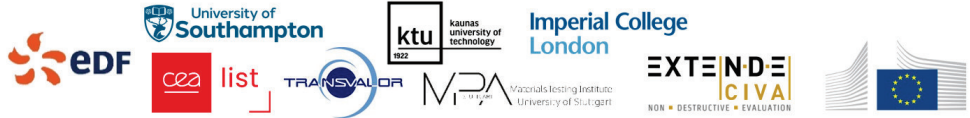
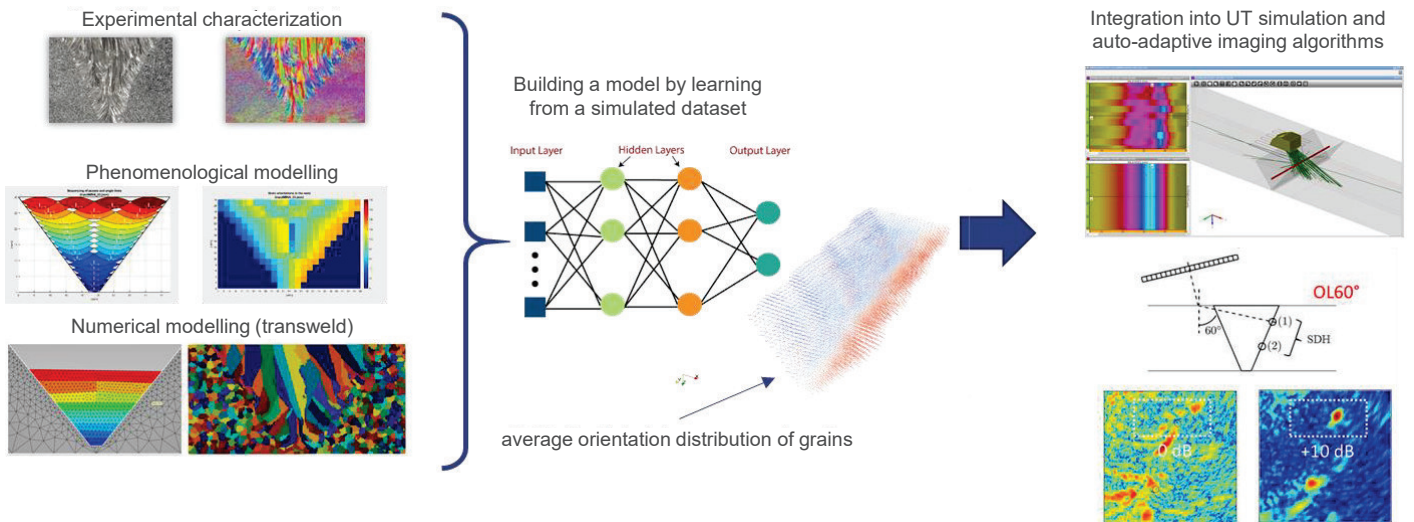




Trends...



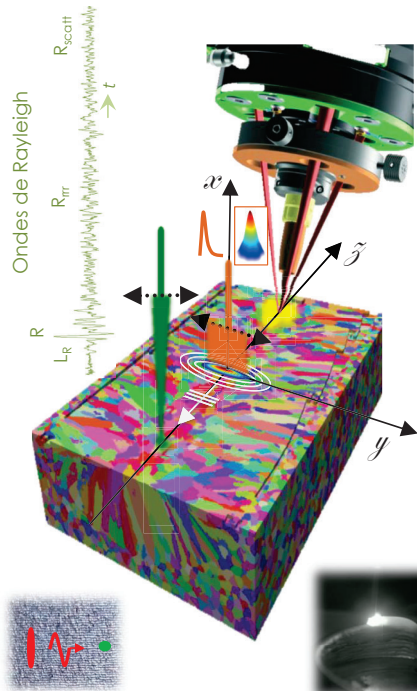
Propose improved simulation and ultrasound imaging tools for imaging welded parts, exploiting knowledge of the material's microstructure



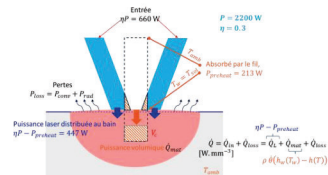
iWeld received funding from the Euratom research and training program 2021-2027 under grant agreement No 101061359

COLUMBO

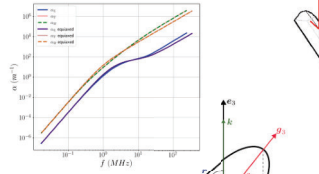
Caractérisation et contrôlabilité multi-échelles par ultrasons-laser de composants WLAM : vers une surveillance en ligne basée sur la physique et augmentée par l'apprentissage automatique



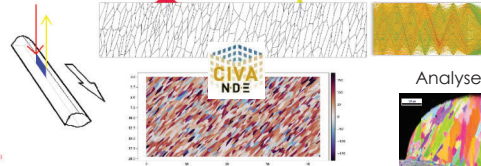
Modélisation et simulation procédé WLAM
 Microstructures virtuelles



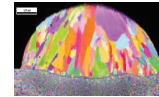
Modélisation Simulation ondes US en milieux complexes



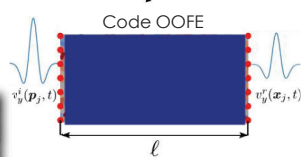
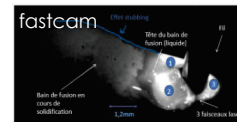
Simulation EF spectraux -> Machine Learning



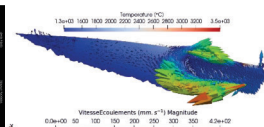
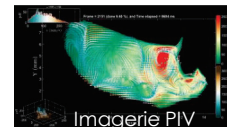
Analyse EBSD



Cellule WLAM LURPA



$$\alpha(f) = -\frac{10}{\ell} \ln \left(\frac{\sum_{j=1}^M |v_0^o(x_j, f)|^2}{\sum_{j=1}^M |v_0^i(p_j, f)|^2} \right)^{1/2}$$



Modelling the influence of mechanical stress

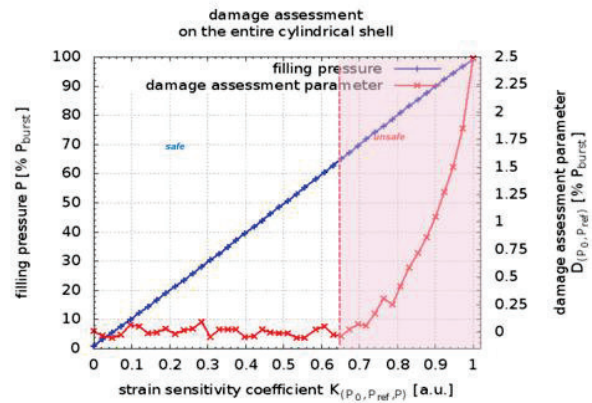
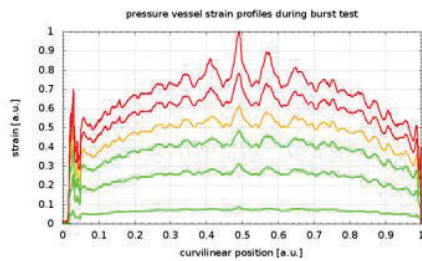


MONITORING OF THE H2 TYPE IV COMPOSITE TANK

H2 tanks in which optical fibers have been co-wound during manufacture. Rayleigh measurement (quasi-static deformation) along the fiber.



Composite tanks with embedded optical fiber sensors



André Dalmora – 30/11/2023 – Digiteo

Direction : Philippe Moireau, INRIA Medisim
Encadrement CEA : Alexandre Imperiale



MEDISIM
Mathematical and Mechanical Modeling

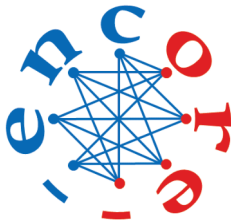
GW4
IM

Horizon 2020
Programme



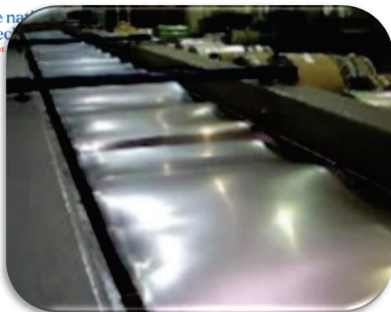
ponents of
imulation

Guided wave tomography for stress characterization

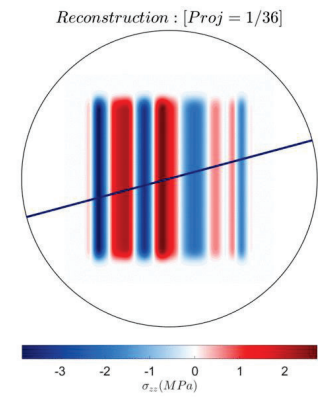
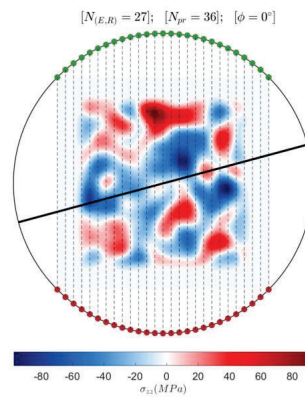


Indirect quantitative characterization of residual stresses Acousto-elasticity (CEA, CETIM) - Magneto-elasticity (GeePs)

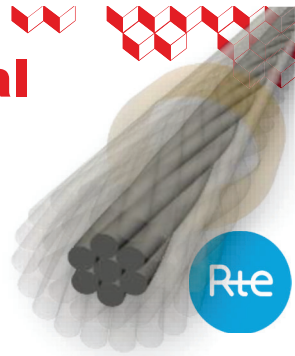
- Sensor adaptation: EMAT and magnetostrictive patches
- Elastic guided wave tomography method



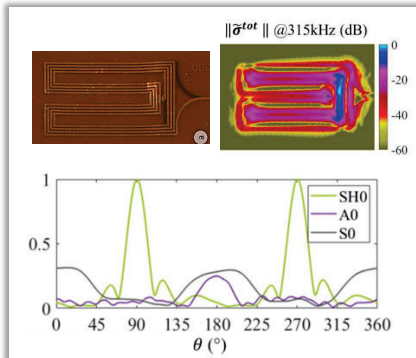
Défaut de planéité pendant le laminage



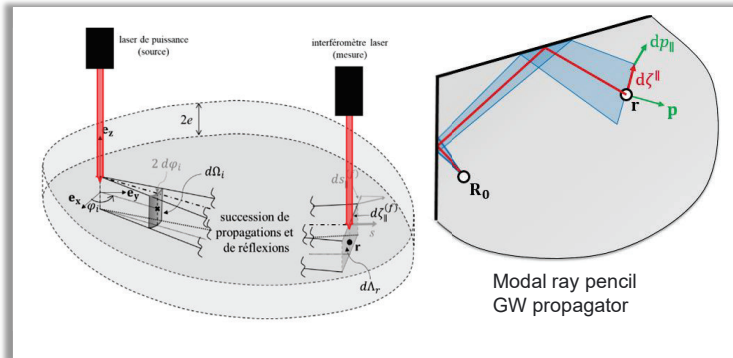
Guided wave simulation with native modal analysis



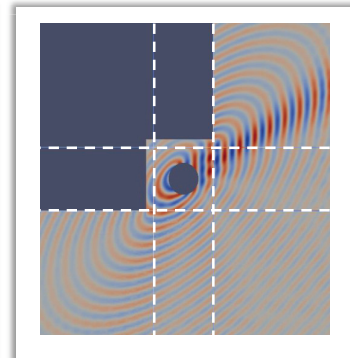
- Modal analysis is critical beyond the fundamental modes in guided waves
- Investigation of innovative semi-analytical models restricted to simple geometries



Mode selection with magnetostrictive patches, Ph.D. G. Cousin, 2021



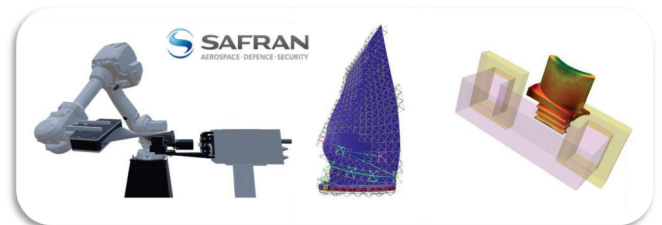
Modal ray pencil propagator
Ph.D. J. Barras, 2020



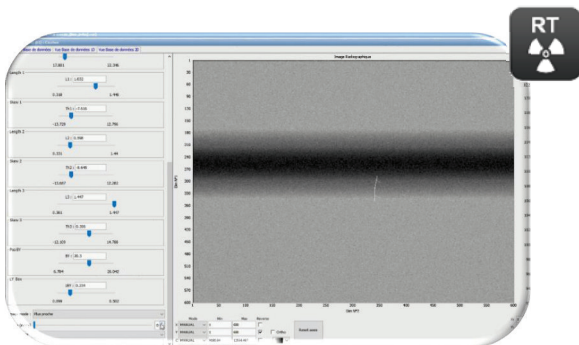
Defect response (FEM box)
Ph.D. A. Allouko
(A.S. Bonnet Ben Dhia, A. Lhémy, V. Baronian)

Trends - Applications

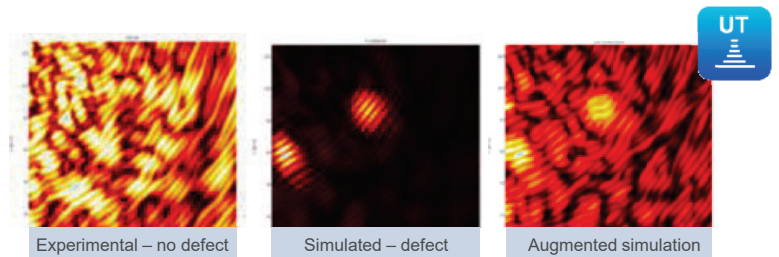
- Influence & characterization of material properties
- Area coverage & optimized robotic inspection
- Augmented imaging with simulated defects



Optimization of the robot trajectory for thermal induction using simulation (3D geometry, BEM)



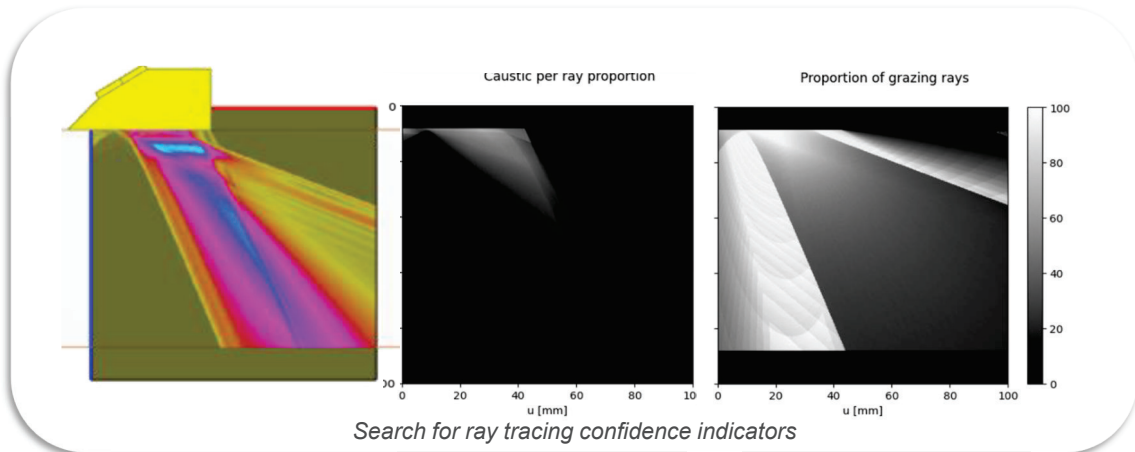
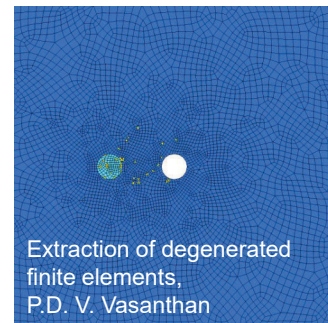
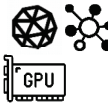
Augmented RX imaging with a simulated defect



Augmented UT simulation by style transfer

Trends - Tools

- Extending FEM capabilities at iso-performance
- Updating semi-analytical tools (fast modal analysis)
- Search for confidence indicators





Thank you for your attention

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