INSTITUT DE SOUDURE

JOURNÉE TECHNIQUE

Les CND des matériaux composites

5 JUILLET 2012

INSTITUT DE SOUDURE
ZI Paris Nord 2 – VILLEPINTE (93)

Organisée par le service Membres industriels

Contribution of numerical simulation to composite parts UT inspections

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(1) EXTENDE (Massy), (2) CEA-LIST (Saclay), (3) EADS IW (Toulouse)

cea list
energie atomique • energies alternatives

EXTENDE
CIVA

EADS

Outline

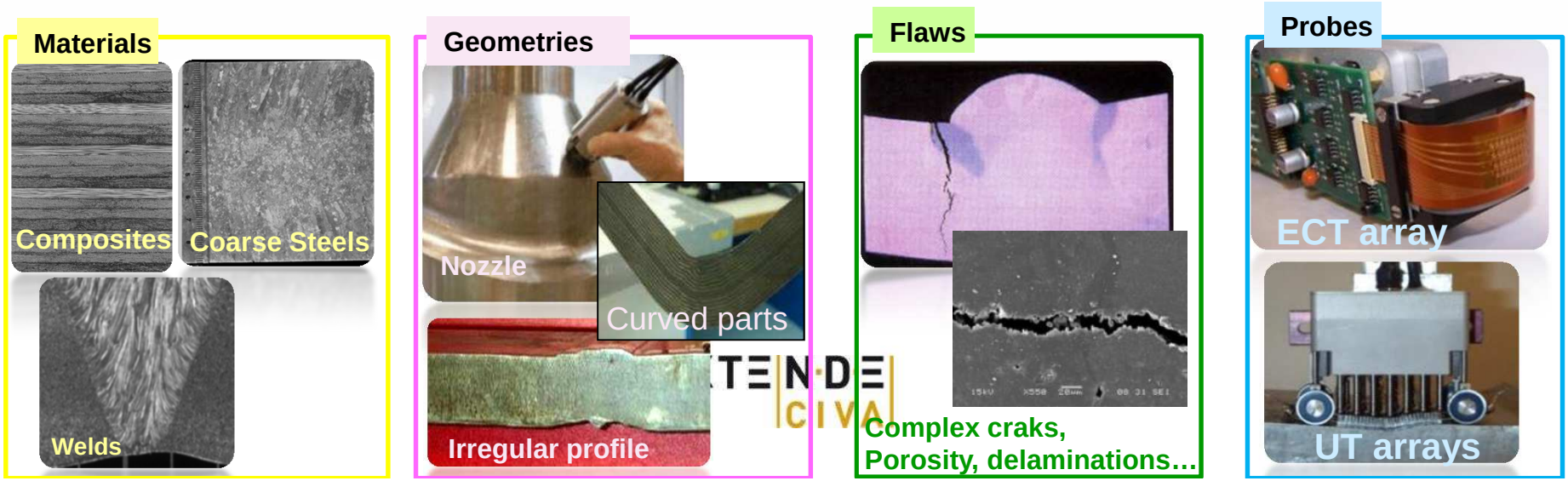
- Context:Benefits of NDT simulation
- NDE simulation: CIVA software
- UT Simulation with composite structures
  - Existing tools in CIVA 10
  - Extension of capabilities in future CIVA release
- Conclusion

EXTENDE CIVA

Benefits of simulating NDT

- **Help for methods and probes design:** Time and cost savings (less prototypes, firm-up choices, etc.)
- **Expertise**: Help the diagnosis in complex situations (Comparison between acquisitions and simulation)
- **Support qualification documentation**
- **Technical support during bid proposal**: "Showing to convince"
- **Training:** Better understanding of physical phenomena

- In a wide range of situations :



NDE Simulation : CIVA software

- Software dedicated to NDE Simulation
- Relies mostly on semi-analytical models (i.e simplified but fast and accurate when applicable)
- Multitechnics:
  - UT: Ultrasonic Testing (Conventional Pulse-Echo, PA, TOFD, Tandem)
  - GWT: Guided Waves Testing
  - RT, CT: Radiography and Computed Tomography (X Rays, Gamma rays)
  - ET: Eddy Current Testing
  - Analysis tool (signal processing, data reconstruction…)
- Developed by the CEA LIST
  - Research Centre in NDE: 100 persons
  - Development and validation of CIVA: 25 persons

cea list
énergie atomique • énergies alternatives

EXTENDE CIVA

EXTENDE

- CIVA Distribution
- Technical support
- Training courses
- Consulting
- Research & Development (3 ANR, 1FP7)

EXTENDE

Method → Simulation → Innovation

Industrial needs

Economic constraints
Environmental constraints

cea list

100 People

Models | Software

Methods | Probes

Network

IMASONIC

M2M

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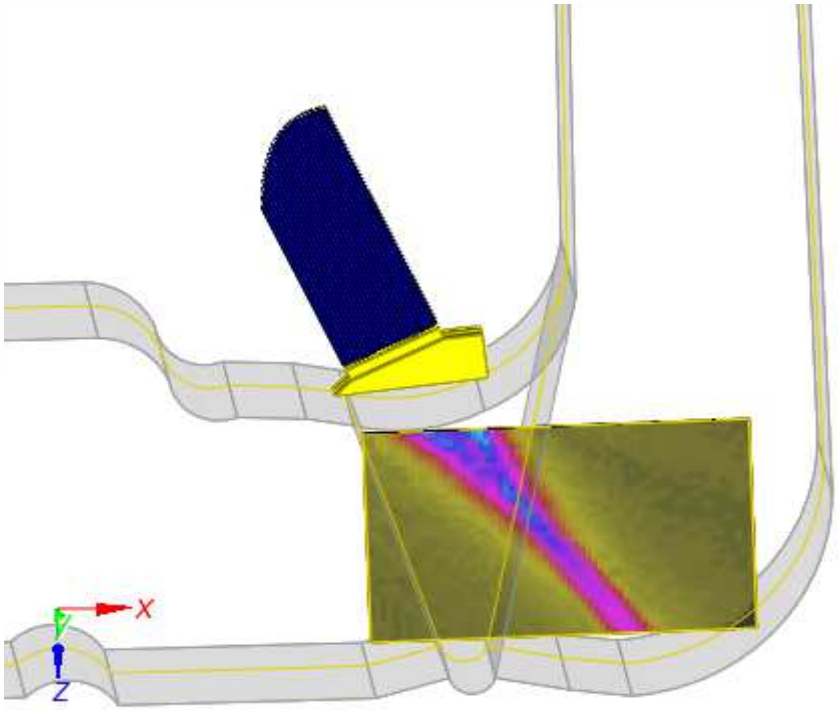
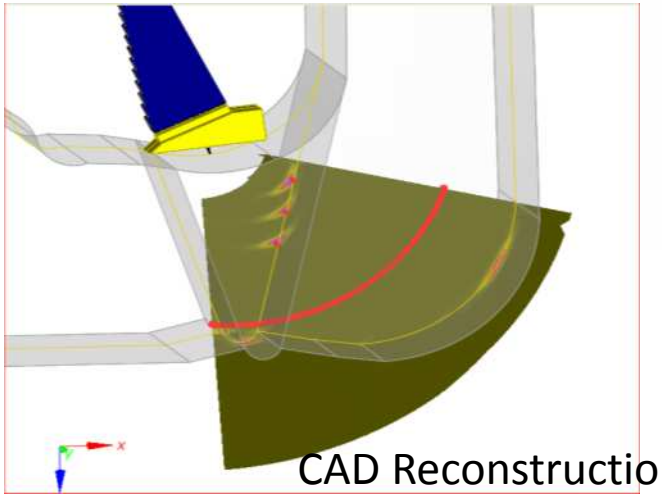
CIVA UT

- Beam calculation:
  - Probe design
  - Zone coverage
- Interaction with defects:

(Ascan, Bscan, Cscan, S-Scan,etc.)

  - Predict inspection performances



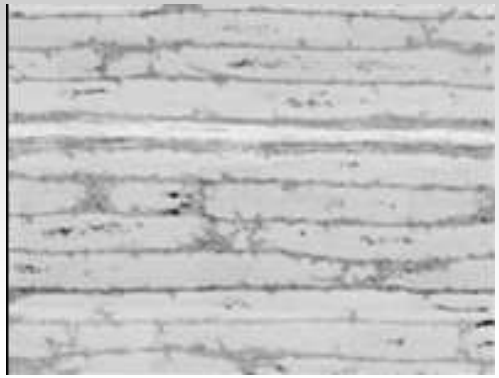


CAD Reconstruction

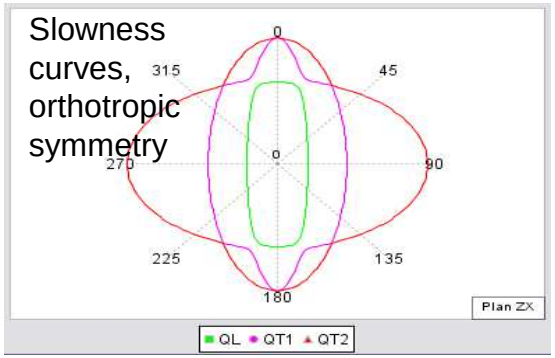
EXTENDE CIVA

UT simulation in composites

- Composite materials :
  - Heterogenous with different scales:
    - Carbon fibers: ϕ ~ 7 µm
    - Plies: from 125 to 250 µm



  - Anisotropic:
    Typical sound speeds for Quasi-Longitudinal waves:
    - ~ 3000 m/s perpendicular to fibers plane
    - ~ 9000 m/s along fiber direction



- Modelling approaches:
  Different strategies may be carried out:
  - Semi-analytical approaches on homogenized parts
  - Pure numerical approaches (e.g. Finite Elements, Finite Differences)
  - Combination of both numerical and semi-analytical approaches

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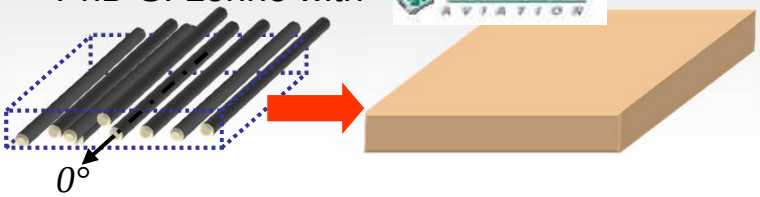
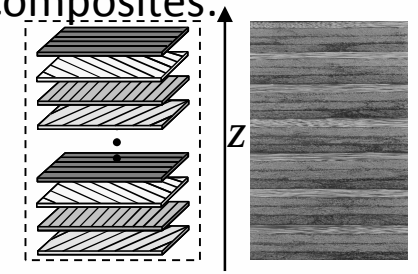
Existing tools in CIVA 10 *(current release)*

- Existing in CIVA 10: Homogenization approach and semi-analytical models :
  - First step: homogenization of the single ply
    - Inputs : matrix + carbon fibers description
    - Outputs : equivalent anisotropic material, accounts for mutliple diffusion by fibers and viscoelastic losses (attenuation)

PhD S. Lonné with DASSAULT AVIATION



  - Second step: homogenization of a multi layered composites:
    - Inputs : Homogenized single ply + stacking pattern
    - Outputs : equivalent anisotropic material



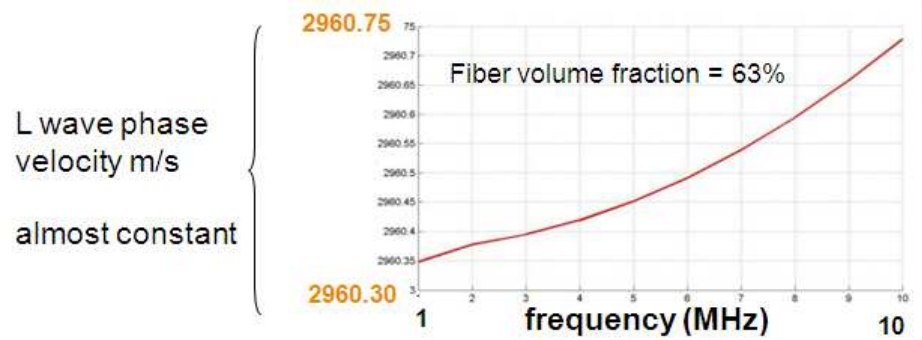
PhD S. Deydier with EADS CCR

- Advantages / Drawbacks:
  - Easy definition of composites using material properties
  - Connexion to beam propagation and defect scattering codes in CIVA
  - Valid for periodic, regular composites (no ply waviness,etc…)
  - Restricted to « quasi » plane composites (flat panels), not for curved composites
  - No structural noise (due to homogenization approaches)
  - Adapted to bulk waves but not to guided waves (wave guide is not homogeneous)

EXTENDE CIVA

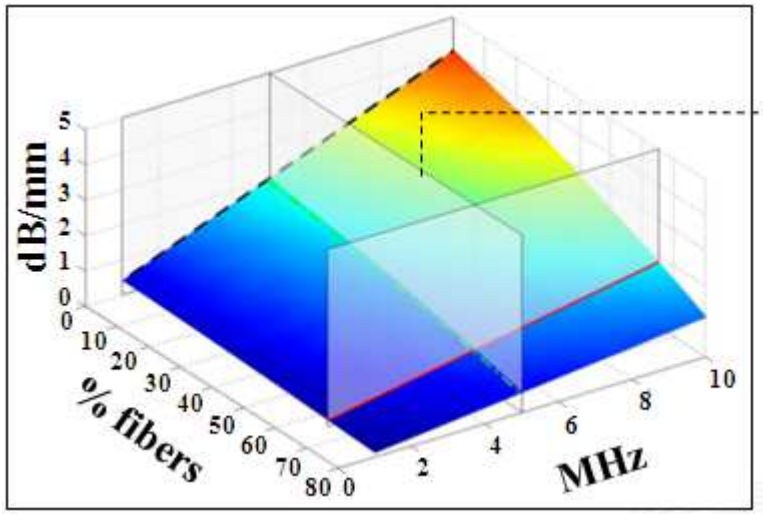
Existing tools in CIVA 10

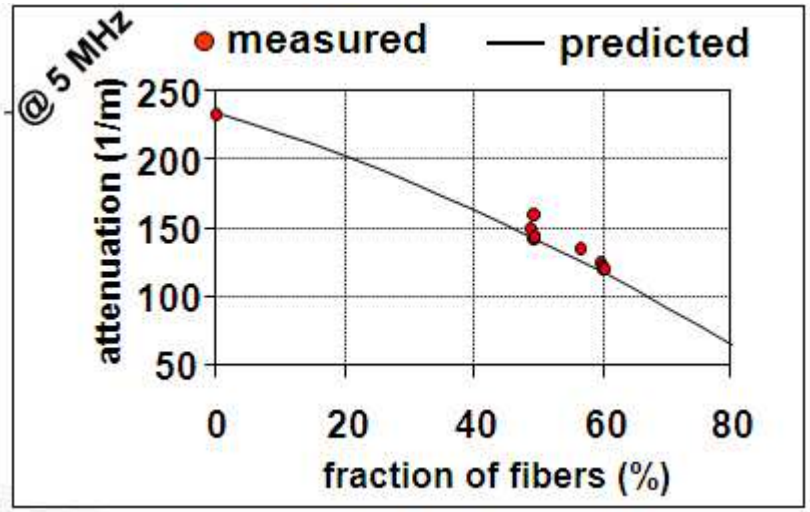
- Single layer composite, results and experimental validation :
  (PhD S. Lonné (2003), Dassault)
  - No dispersion of Longitudinal waves (similar behavior for SV and SH waves) :



  - Attenuation of Longitudinal waves (similar behavior for SV and SH waves):

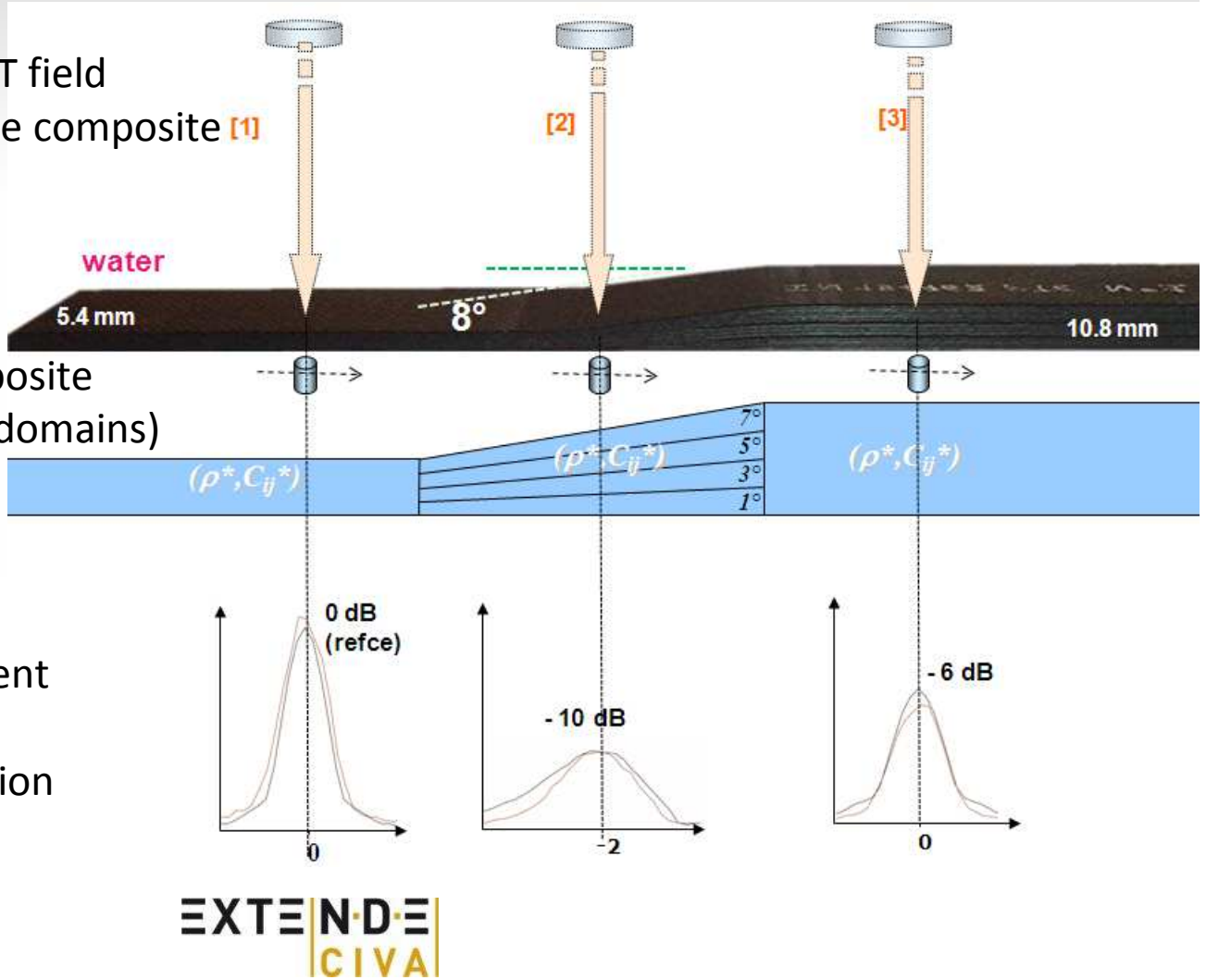
Linearly dependent on frequency Decreases as %fibers increases





Existing tools in CIVA 10

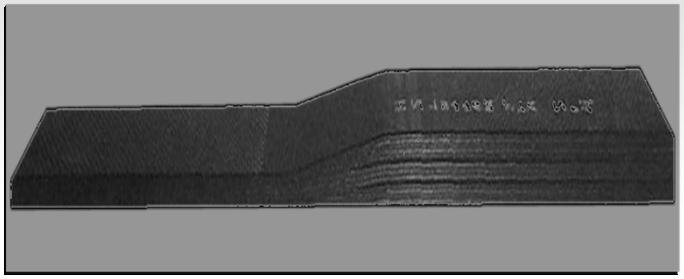
- Multiple layered composite, results and experimental validation :
  (S. Deydier (2006), EADS)
  - Measurement of the UT field transmitted through the composite
  - Simulation of the composite (several homogenized domains)
  - Good agreement Simulation/Measurement regarding UT beam deviation and attenuation



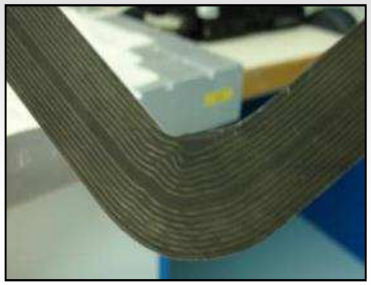
EXTENDE CIVA

Composites inspection: Industrial issues

- Complex structures and geometries :



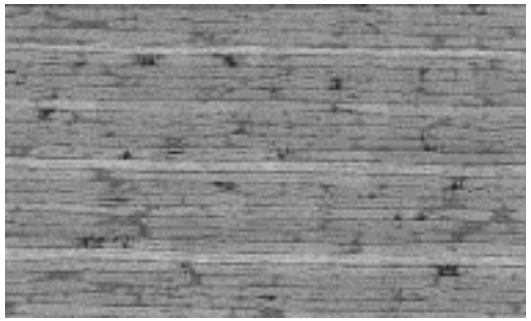
Thickness variations



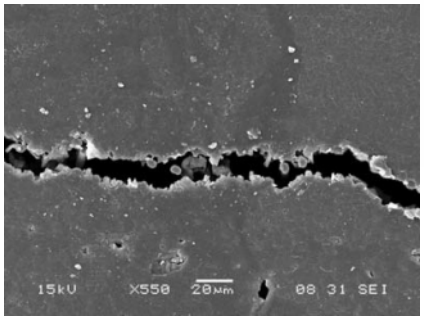
(Highly) curved parts

Stiffened panel

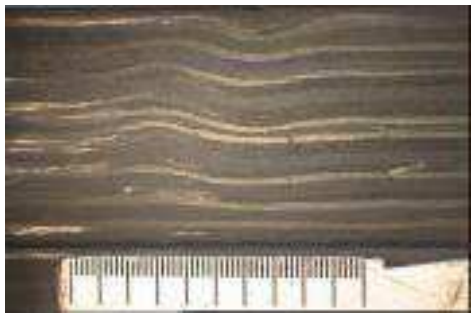
- Specific defects to be assessed in composite structures



Porosity (black)



Delaminations



Ply waviness

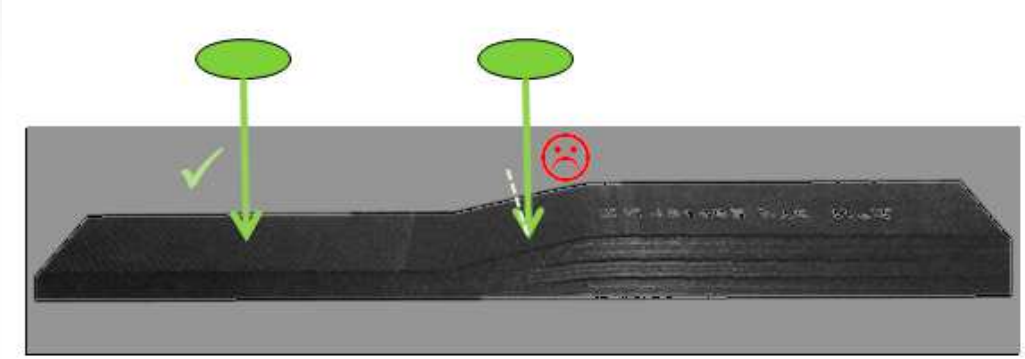
- Complex phenomena (noise, etc.)

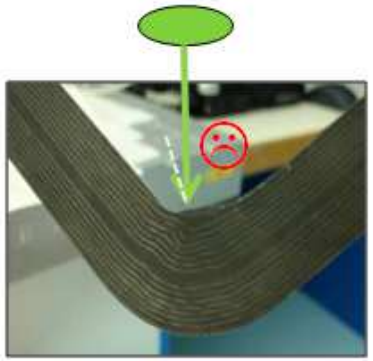
EXTENDE CIVA

Composites inspection: Industrial issues

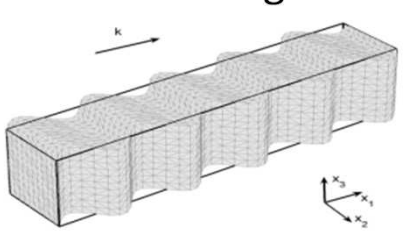
Modeling has to tackle these issues

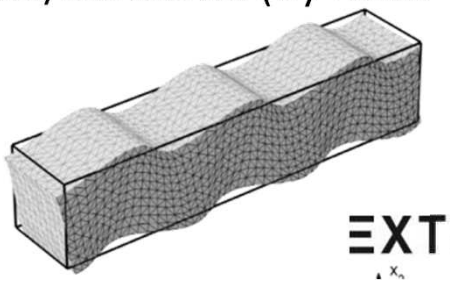
- Bulk waves inspection:
  - Most conventional technique : 2D scanning with L waves perpendicular to the structure
  - Drawbacks: Difficulty to keep 0° incident waves on complex and curved parts





- Guided Waves testing :
  - Long range inspection (restricted scanning) of a structure
  - Drawbacks: Complex interpretation of the response due to multiple and dispersive *modes generated/scattered* (by flaws and/or structures eg stiffeners)





EXTENDE CIVA

Extension of capabilities in future CIVA release

- Accounts for ply waviness, complex defects, etc.
  - Homogenization and semi-analytical formulation cannot take account of the full complexity of the configurations
  - Hybrid approach: Coupling of Semi-analytical model (CIVA « conventional ») and numerical models: « ACEL-NDT » Finite Difference tool by EADS IW (N.Dominguez)

EADS

- Noise simulation:
  - Development of a semi analytical model

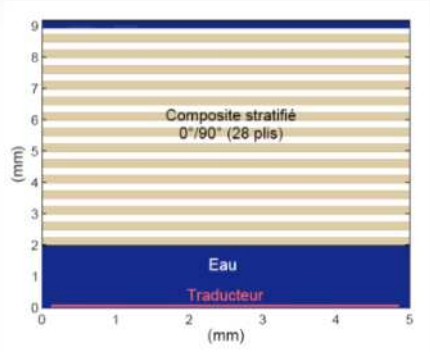
- Extension of the GW module to composite inspection *(today, only metallic parts in CIVA GW)*

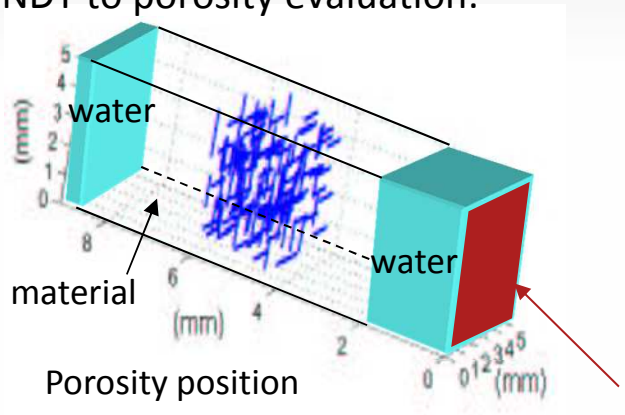
EXTENDE CIVA

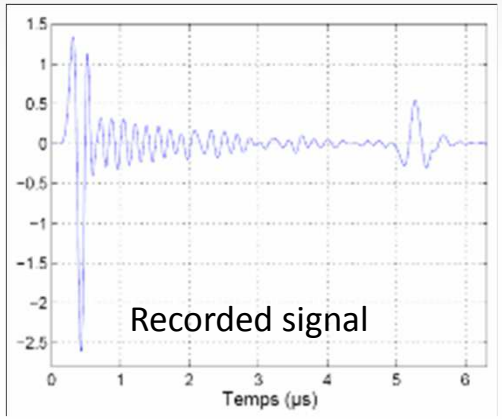
Coupling with ACEL-NDT

ACEL-NDT

- Numerical model: Finite Difference Time Domain Simulation (FDTD)
- Developed by EADS Innovation Works (N.Dominguez)
- Application of ACEL-NDT to porosity evaluation:

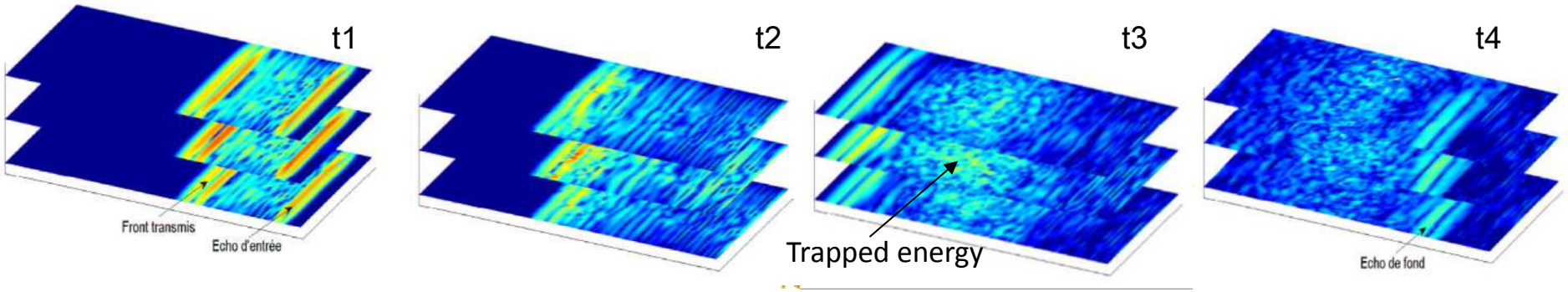






Transmission/Reception transducer

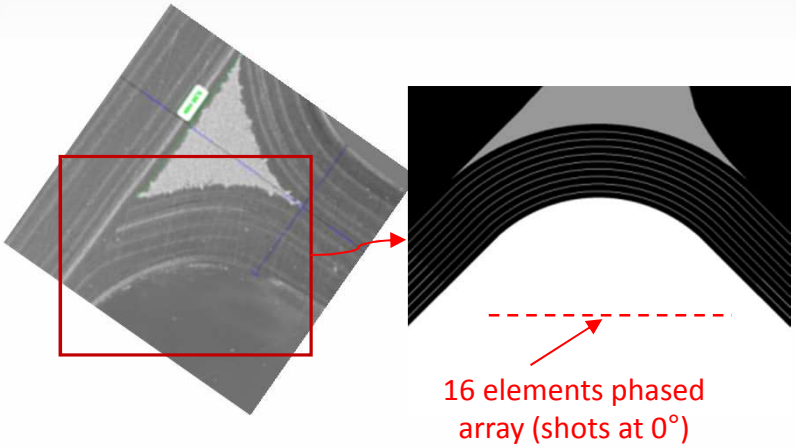
Snapshots of wave propagation



Coupling with ACEL-NDT

ACEL-NDT

- Numerical model: Finite Difference Time Domain Simulation (FDTD)
- Developed by EADS Innovation Works (N.Dominguez)
- Application of ACEL-NDT to curved composite :



Geometry definition
Description at the ply scale

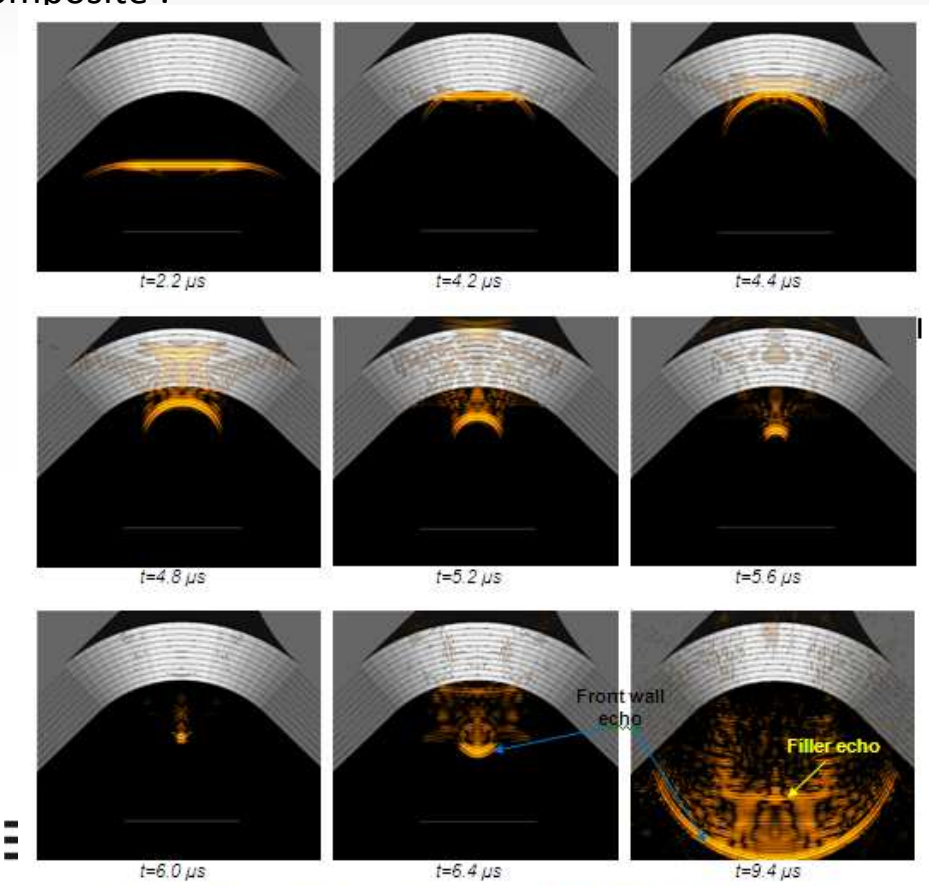


Figure 15 – Snapshots of ultrasonic propagation for the shot at 0° in log scale with 30 dB dynamic range

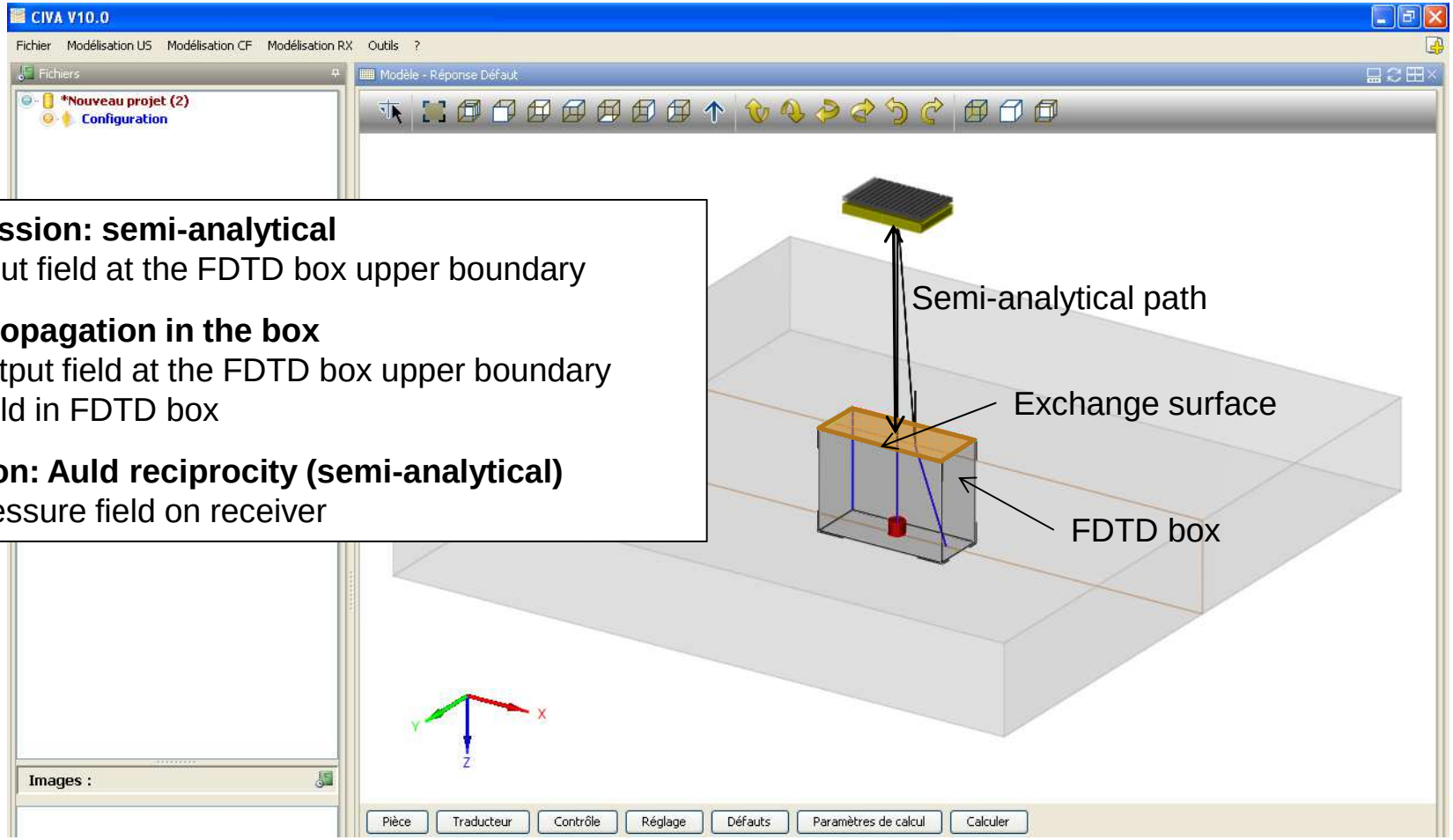
Numerical methods:

- Accounts for all phenomena
- But may be time consuming

Coupling with ACEL-NDT

CIVA/ACEL-NDT: Hybrid approach and integration in CIVA platform

- Idea: Benefit from the versatility of numetical approach, from the rapidity of semi-analytical approach and from the NDT-oriented interface of CIVA (easiness of use)
- Development and integration of a hybrid code: **CIVA/ACEL-NDT**

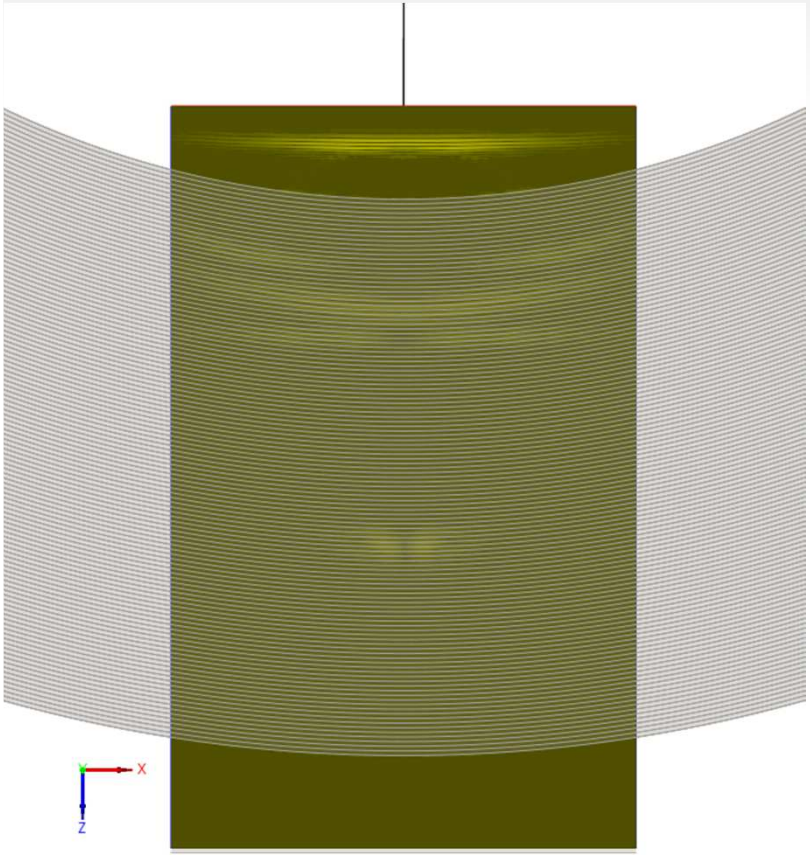


1. **Transmission: semi-analytical**
   → Input field at the FDTD box upper boundary
2. **FDTD propagation in the box**
   → Output field at the FDTD box upper boundary
   \+ Field in FDTD box
3. **Reception: Auld reciprocity (semi-analytical)**
   → Pressure field on receiver

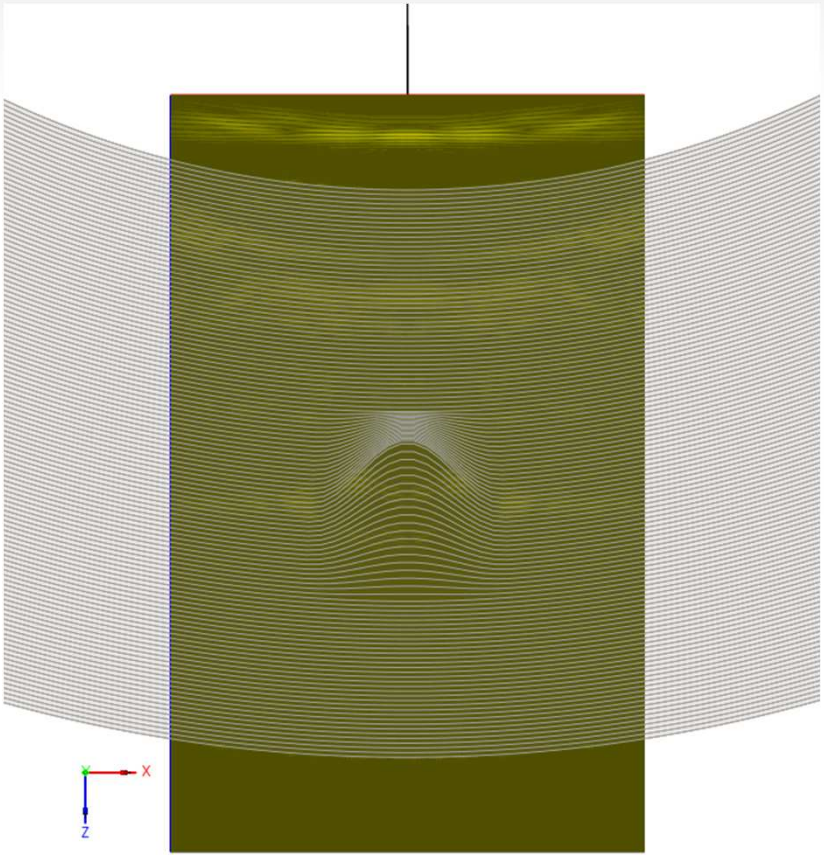
Coupling with ACEL-NDT

- CIVA/ACEL-NDT: Example of simulation results:

Propagation through a « safe » part



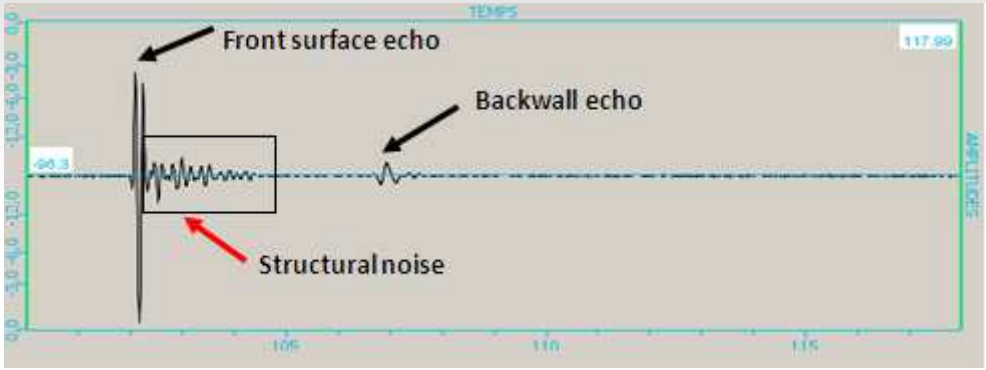
Propagation through a part with ply waviness



EXTENDE CIVA

Noise modeling

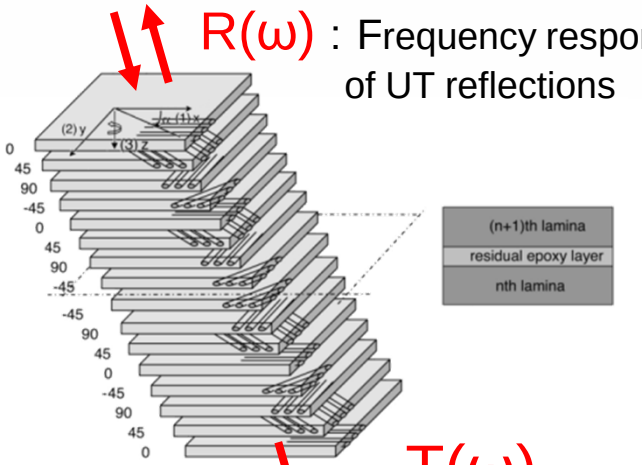
- Experimental observations : Presence of structural noise on composites :
  - The noise level strongly depends on probe's frequency
  - Possibility to « hide » the echo from a defect (near the surface)
  - It also alters the backwall echo spectrum contents



- Origin of this phenomenon : Inter-ply resonance effects.

- Development of a noise simulation code
  - Account of multiple reflexions in a periodic pattern
  - Flat composite
  - Incident plane wave

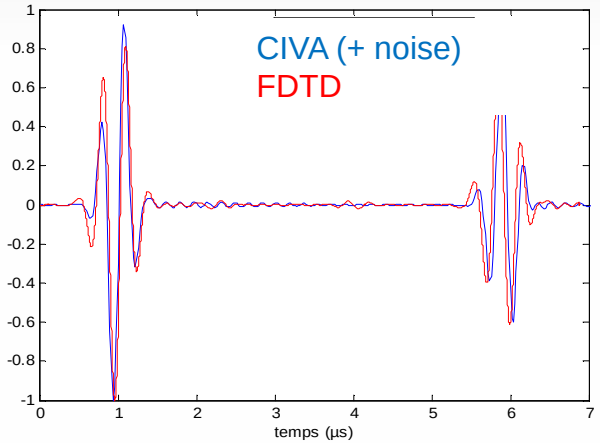
(based on Wang & Rokhlin, JASA, 2003)

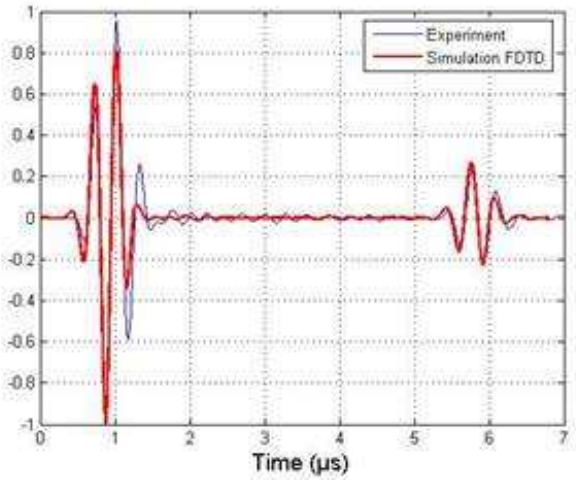


Noise modeling

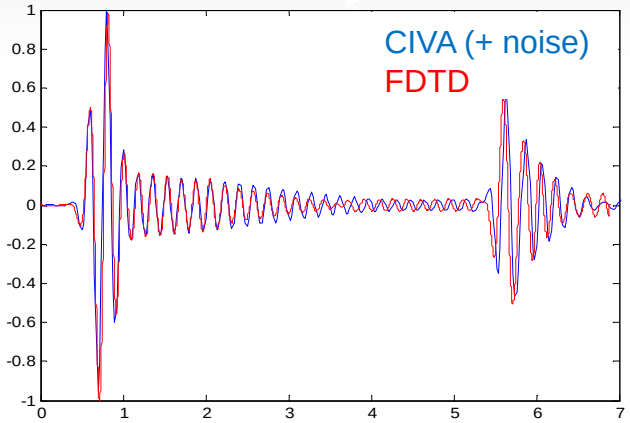
- Validation:
  - CIVA model and FDTD Numerical model (ACEL-NDT)
  - FDTD (ACEL-NDT) and Experiment

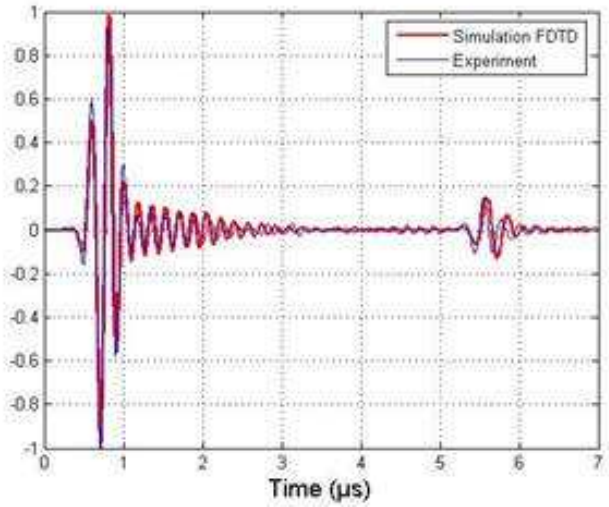
Probe 3.5 MHz





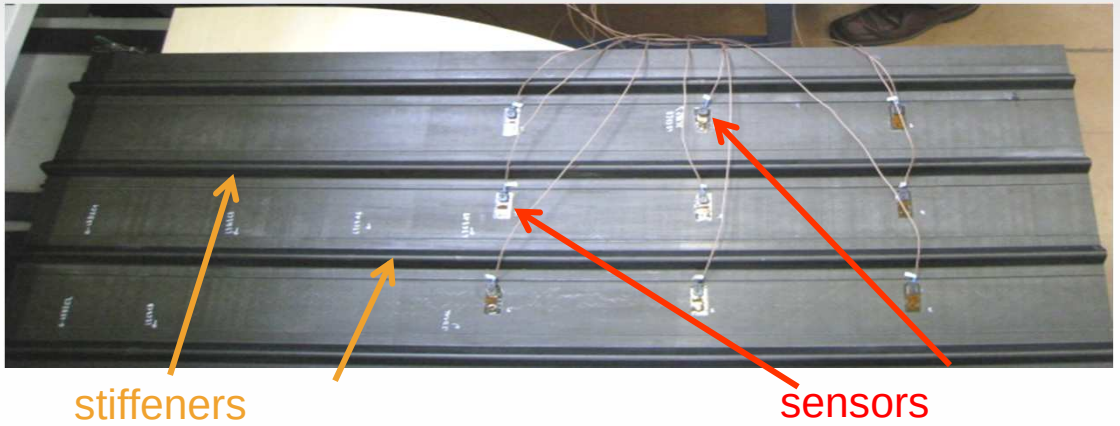
Probe 5 MHz





Guided Waves and Structural Health Monitoring

- Extension of CIVA GW to composite structures:
  - Application case: Evaluation of GW inspection of large stiffened structures



  - Advantages: Long range inspection with no-need to scan the part, possibility to monitor the structure with embedded sensors (SHM)
  - Drawbacks : Very complex signals (multiple modes + velocity dispersion)

  - Needs for simulation: Predict the modes that propagate and with which energy
  - Extension of the SAFE method already used in CIVA GW to the simulation of guided waves in sitffened plates (SAFE: Semi-analytical along the progation direction and FEM in composite cross section)

EXTEND CIVA

Guided Waves and Structural Health Monitoring

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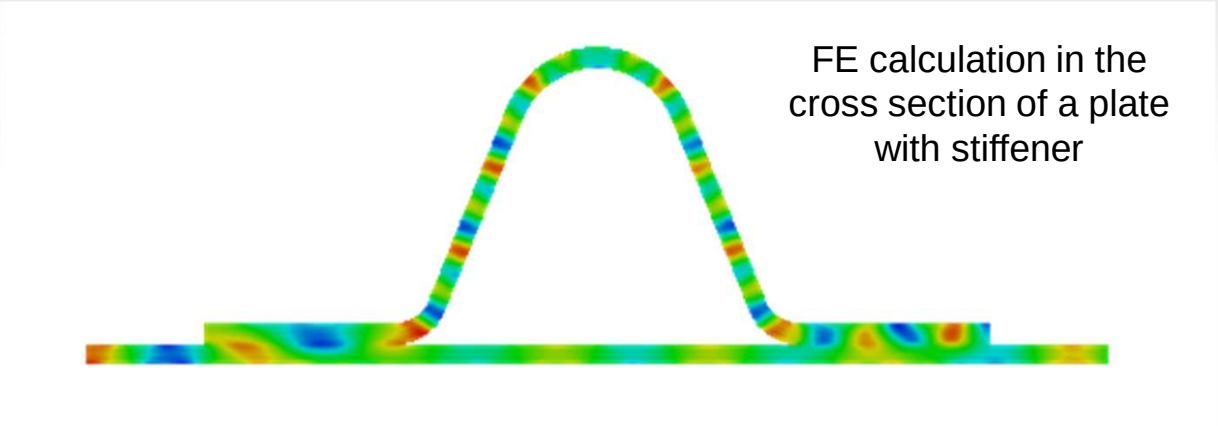

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EXTEND CIVA

Conclusion

- CIVA: The NDT dedicated simulation platform
  - Multitechnics: UT, GWT, RT, CT, ET
  - Provides tools to the industry for a cost-efficient approach of NDT
  - Provides tools to better understand phenomena involved in NDT
- CIVA 10 for composites
  - Existing models: Homogenizes multilayers structures to allow purely semi-analytical calculations with bulk waves: Fast but some limitations
  - Composite industrial applications often faces more complex geometries and phenomena
- Extension of CIVA capabilities:
  - CIVA/ACEL-NDT: Hybrid approach to account for complex plies arrangement (ply waviness) and typical composite defects
  - Development of a semi-analytic « noise » model (inter plies resonance)
  - Extension of CIVA GW to composites

EXTENDE CIVA