Sicherheit in Technik und Chemie

23-24 February 2017

NUMERICAL INVESTIGATIONS FOR AIRBORNE ULTRASONIC INSPECTION OF FIBER-REINFORCED PLASTIC

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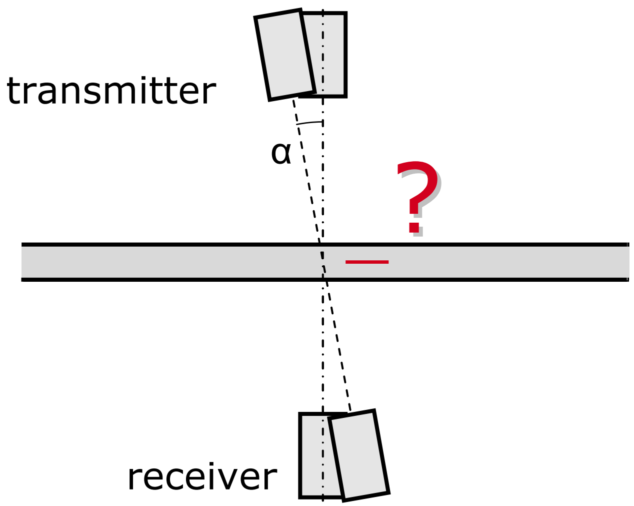
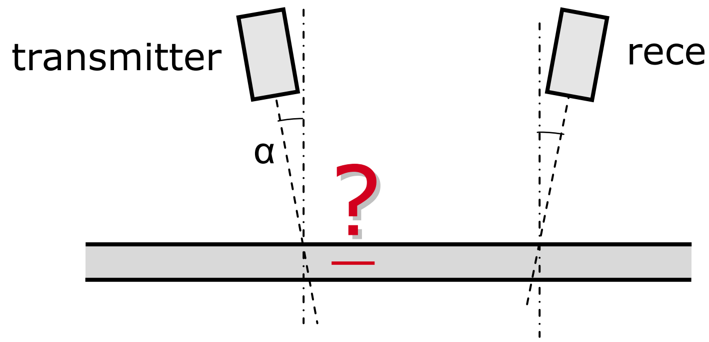
Our motivation: wave propagation in CFRP during air-coupled UT





What happens in the plate?

Overview

Introduction to air-coupled ultrasonic testing

FEM for air-coupled UT on fiber-reinforced plastic

Parameter studies

Summary

Introduction to air-coupled ultrasonic testing (ACUT)

Applications of ACUT

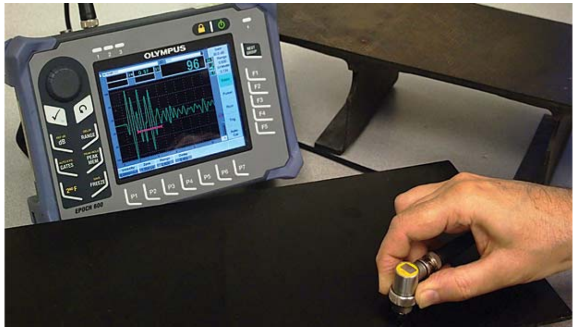
Lightweight materials:
CFRP, GFRP, sandwich structures,
metal adhesive joints

Flaws:
delaminations, impact damage,
pores, ondulation, air pockets,
missing adhesive

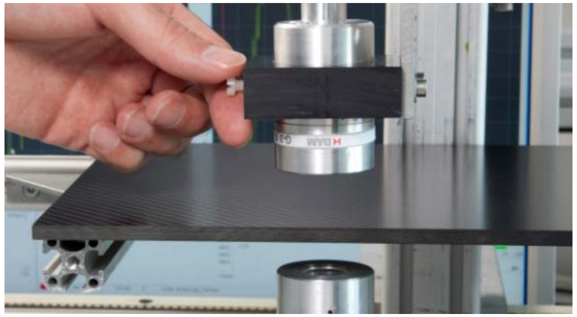
Airbus A350
(Source: reinforcedplastics.com)

Benefits of air-coupled versus fluid-coupled UT

Fluid-coupled UT:
- Better impedance match, higher signals



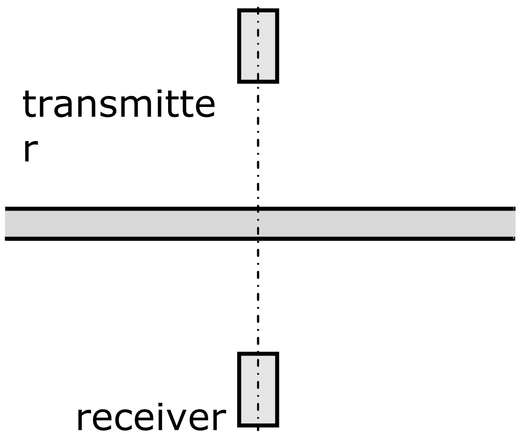
Air-coupled UT:
- Couplant cannot damage the object
- Easyer maintenance
- Uniform coupling

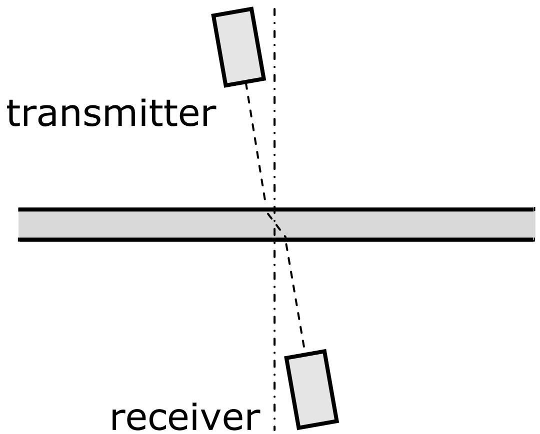


Common misconceptions

Through transmisson: ~~Longitudinal waves~~

Slanted mode transmisson: ~~Shear waves~~

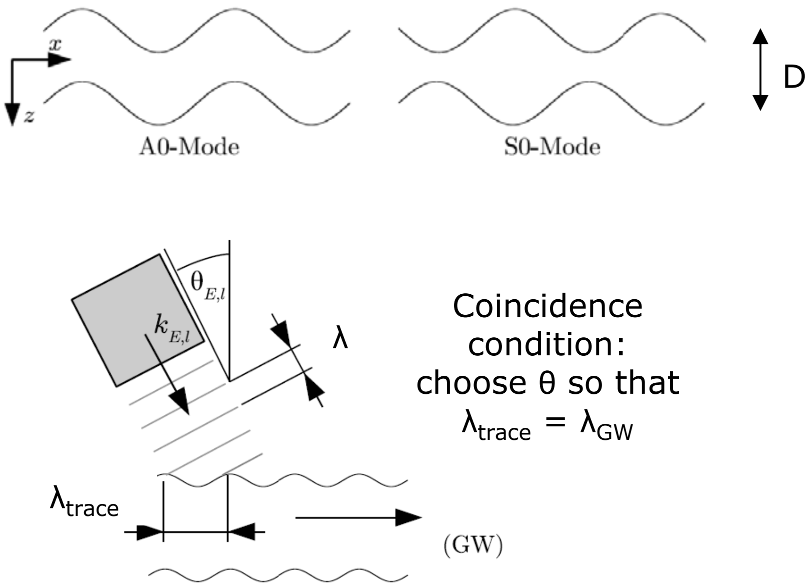




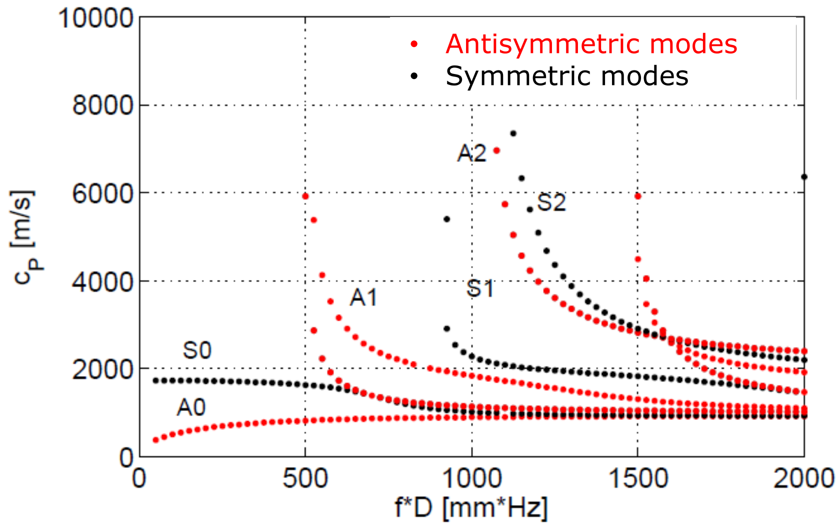
Typical ACUT frequency:
250 kHz

Bulk waves in epoxy resin:
λ_{Long} = 12 mm

Excitation of guided waves

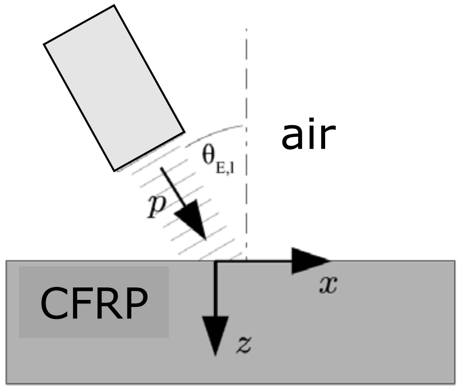


Coincidence condition:
choose θ so that
$\lambda_{trace} = \lambda_{GW}$

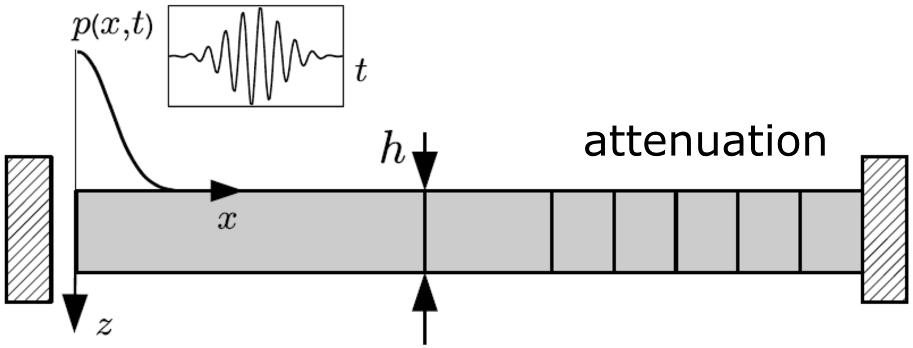


FEM for air-coupled UT on fiber-reinforced plastic

Model for the FEM



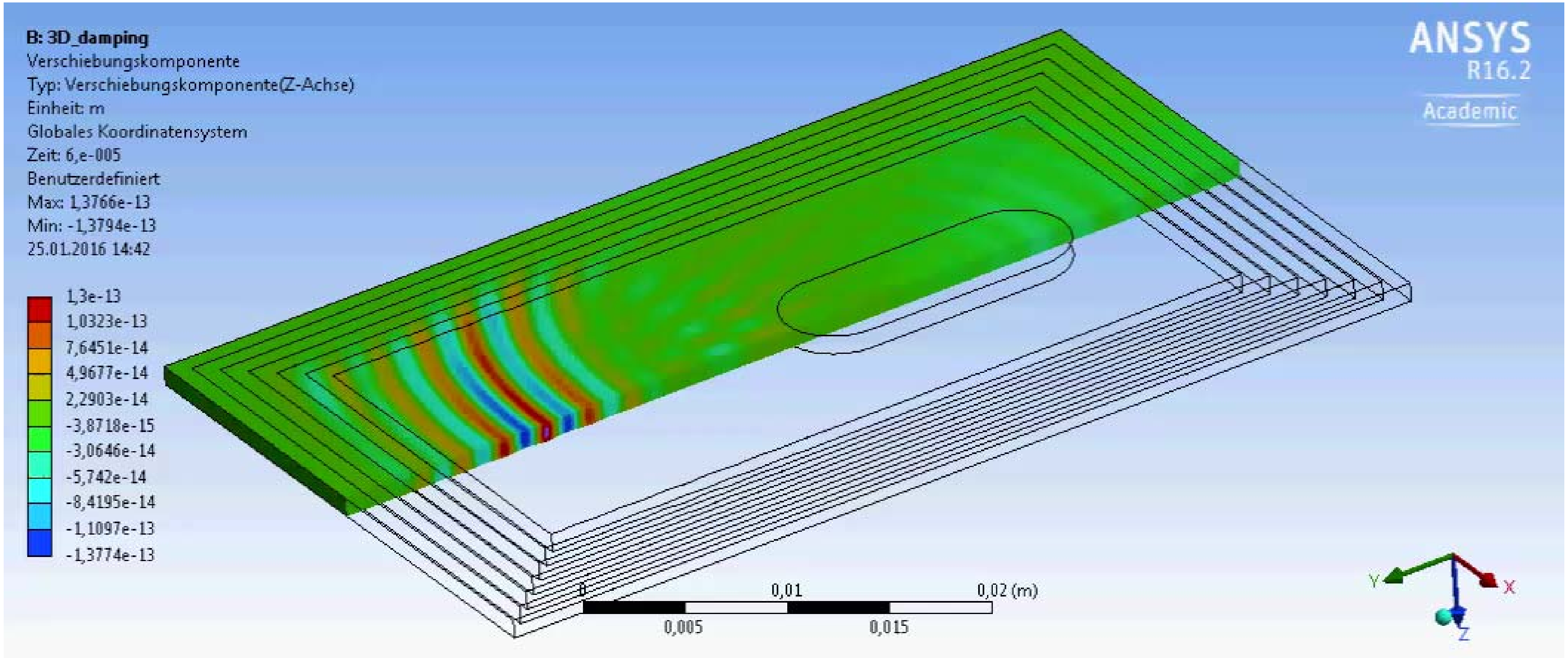
Boundary conditions (for θ=0)



- Cross-ply laminates
- Thickness 4 to 5 mm
- Frequency ≈250 kHz

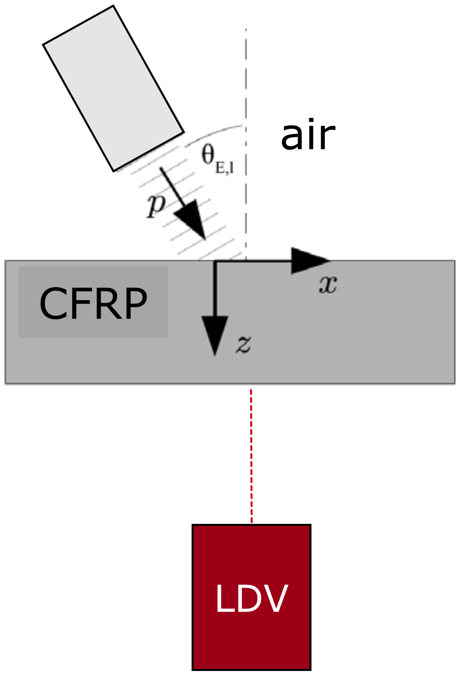
- ANSYS
- Classical laminate theory

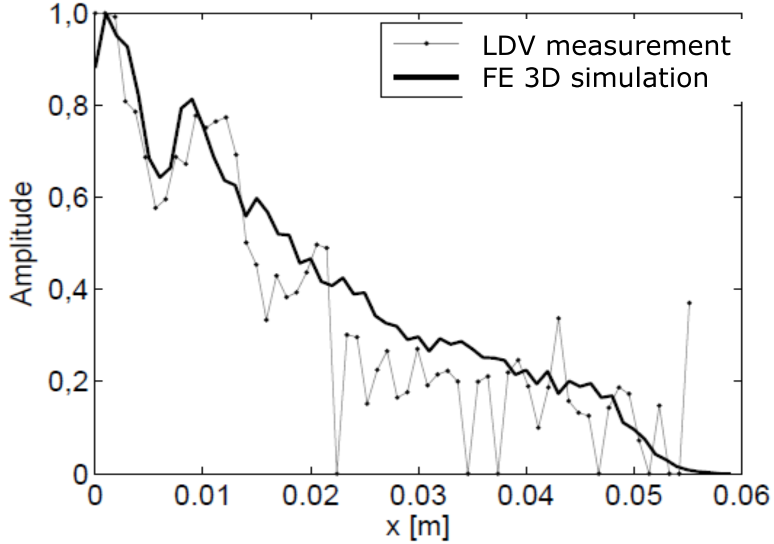
Video



B: 3D_damping
Verschiebungskomponente
Typ: Verschiebungskomponente(Z-Achse)
Einheit: m
Globales Koordinatensystem
Zeit: 6,e-005
Benutzerdefiniert
Max: 1,3766e-13
Min: -1,3794e-13
25.01.2016 14:42
1,3e-13
1,0323e-13
7,6451e-14
4,9677e-14
2,2903e-14
-3,8718e-15
-3,0646e-14
-5,742e-14
-8,4195e-14
-1,1097e-13
-1,3774e-13
ANSYS
R16.2
Academic
0
0,01
0,02 (m)
0,005
0,015
Y
X
Z

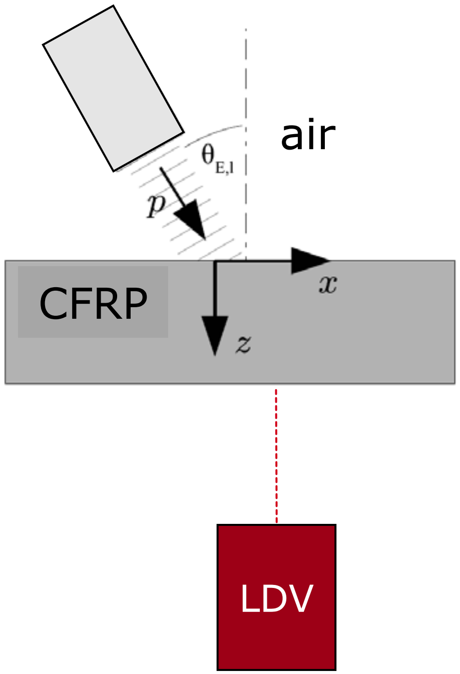
Validation using laser Doppler vibrometry

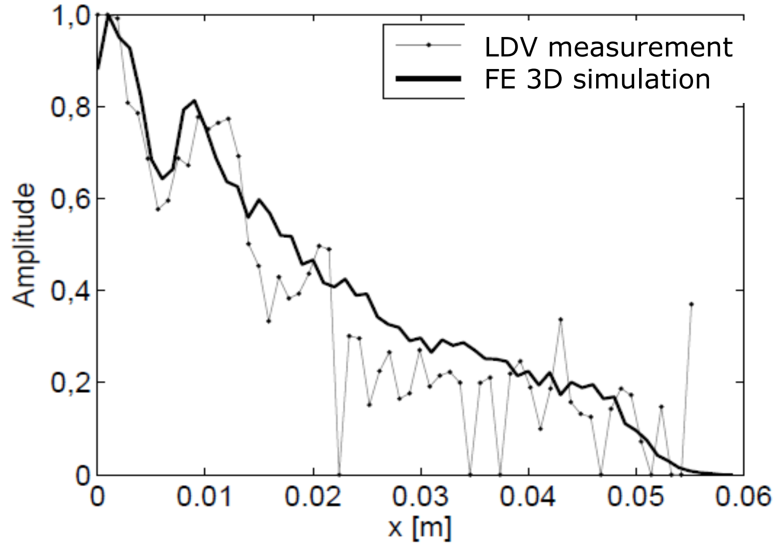




Laser Doppler vibrometer measures the displacement at the lower side

Validation using laser Doppler vibrometry





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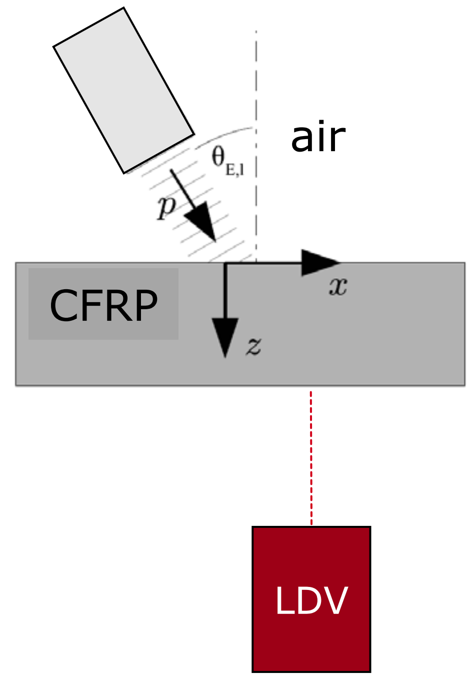

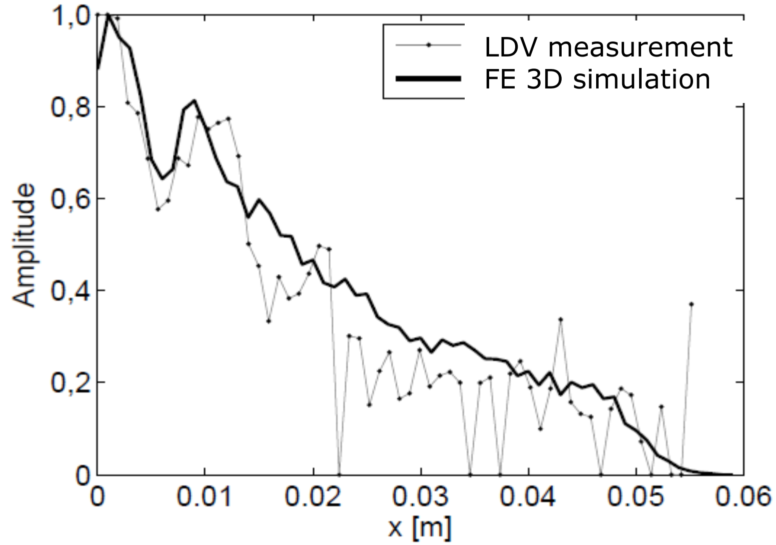

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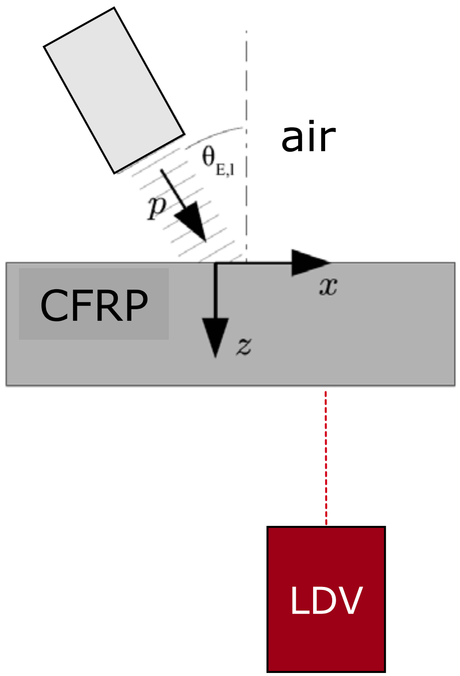
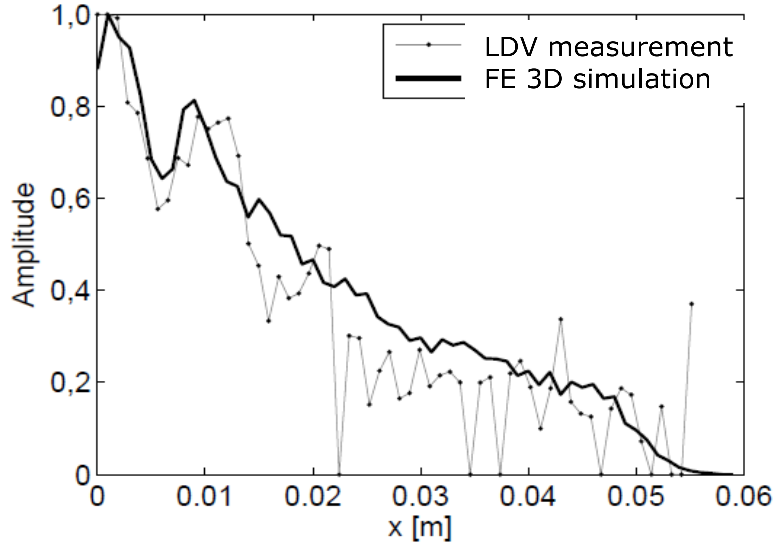
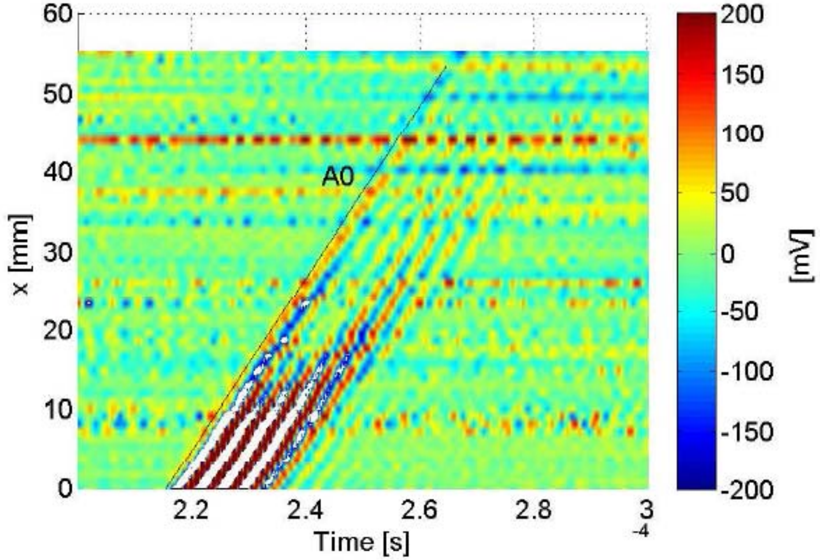




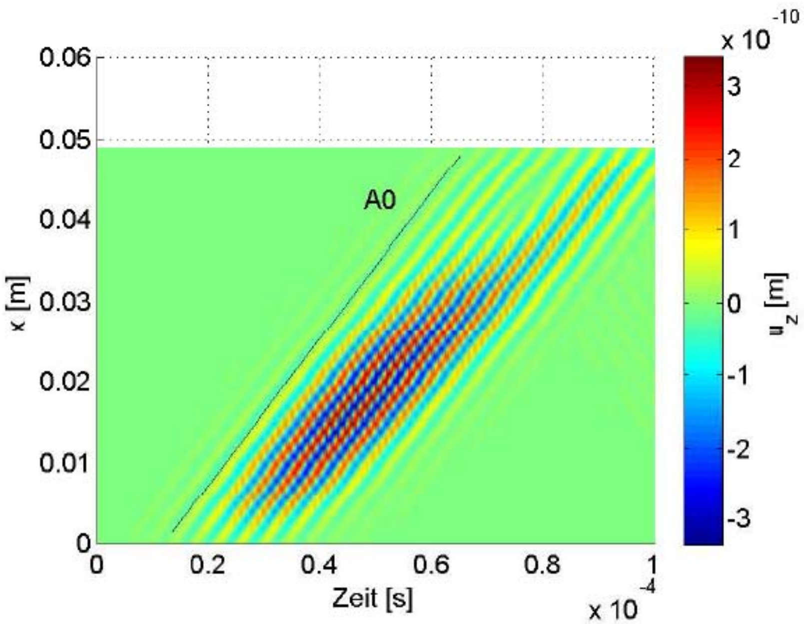
Laser Doppler vibrometer measures the displacement at the lower side

Validation on isotropic epoxy resin

LDV „B-Scan"



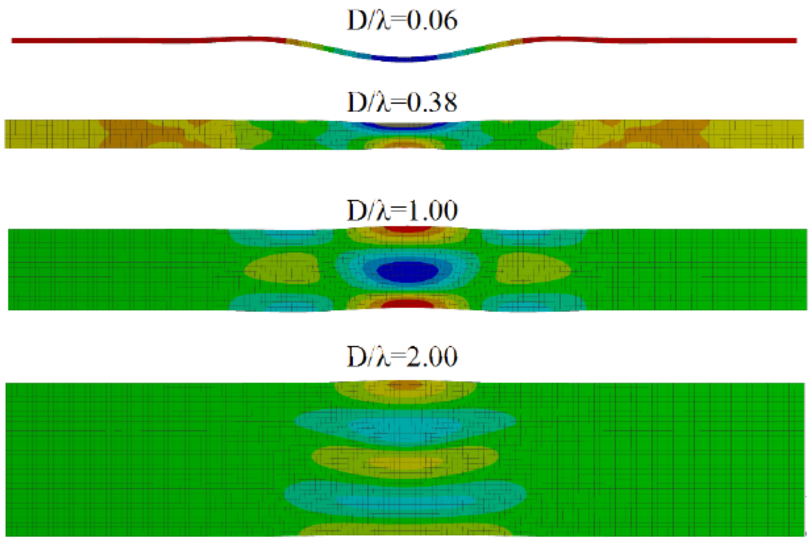
2D FEM



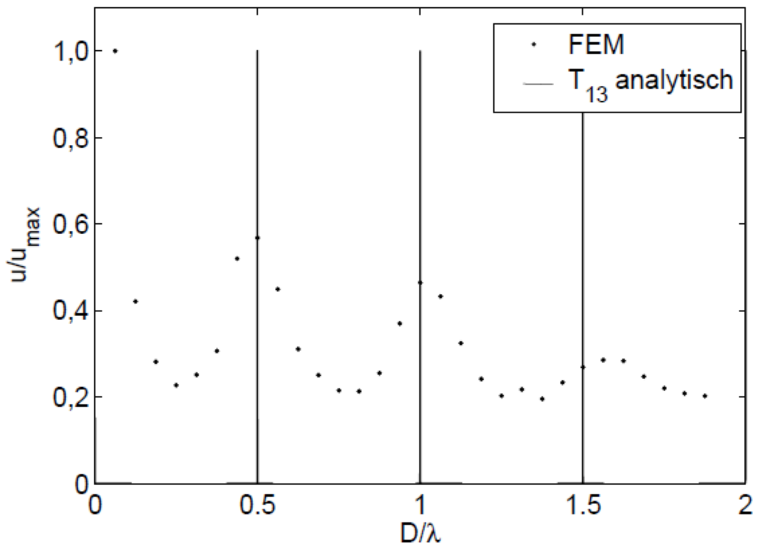
Parameter studies

Through transmission on isotropic epoxy resin

Varied thickness (2D FEM)



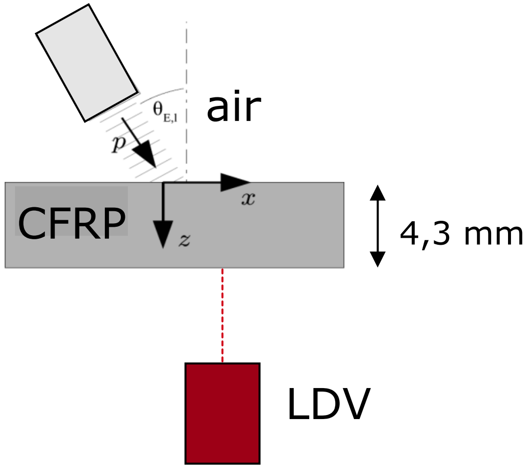
Displacement at the lower side

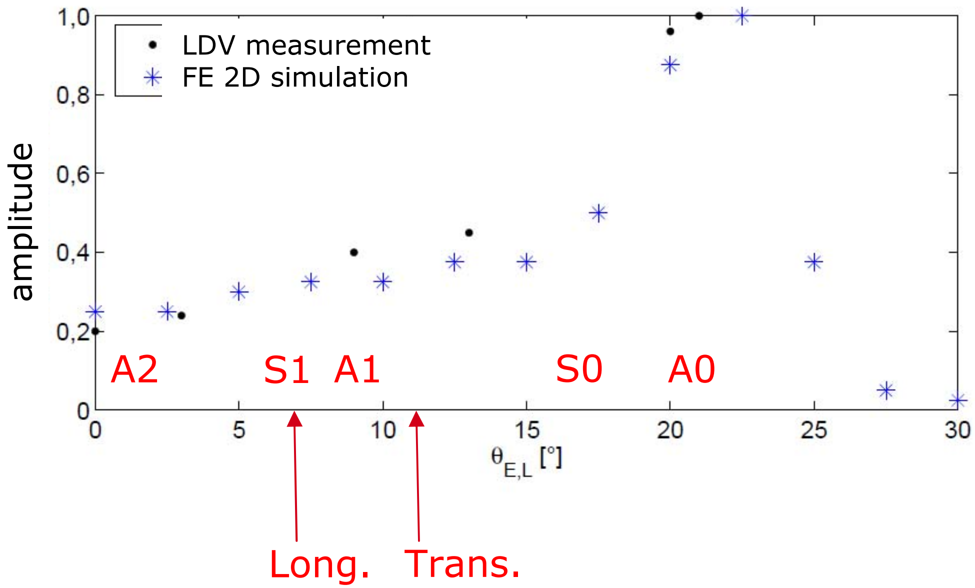


Through transmission of aluminium plate

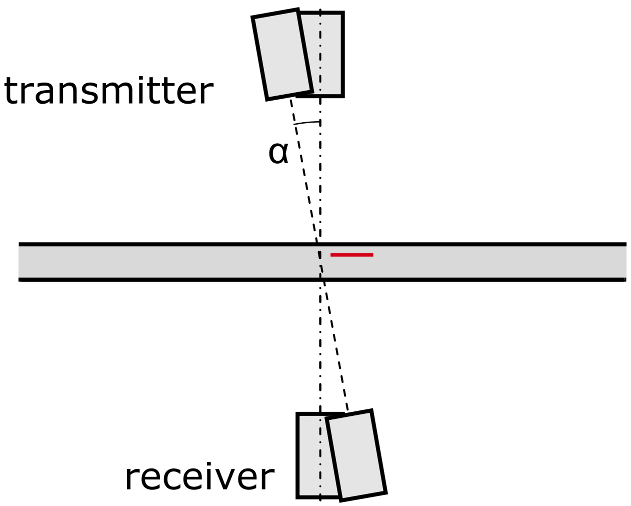
Through transmission on epoxy resin using planar 240kHz transducer

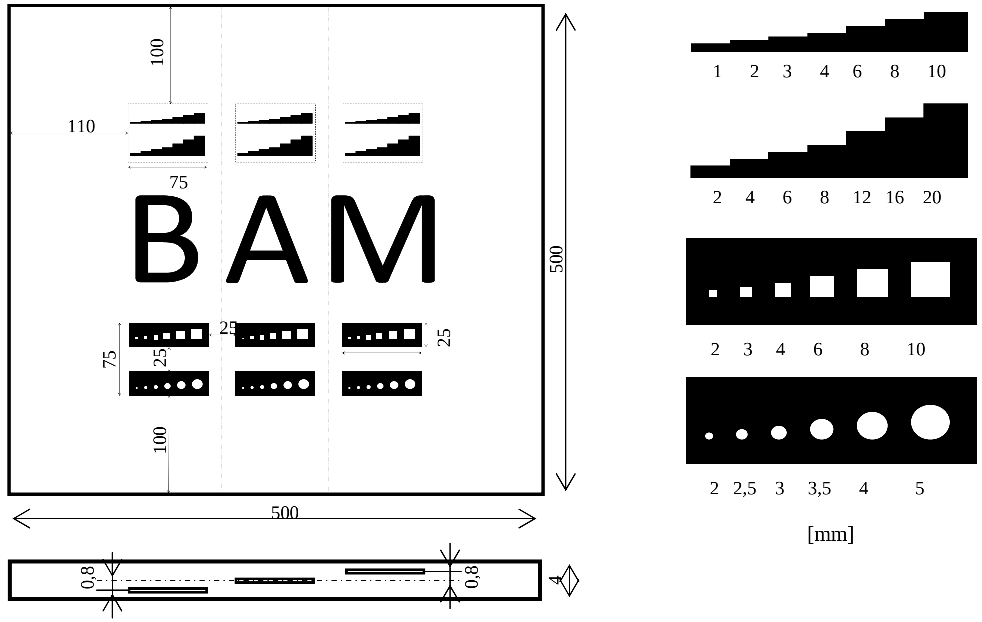
Varied angle of incidence





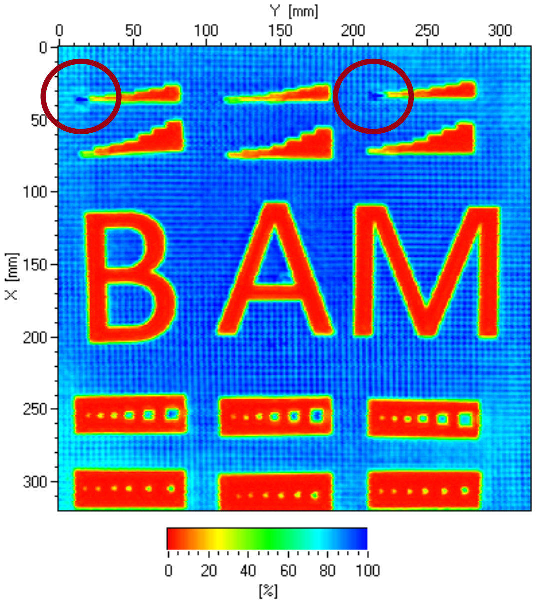
Case study:
Signal increase at some delaminations



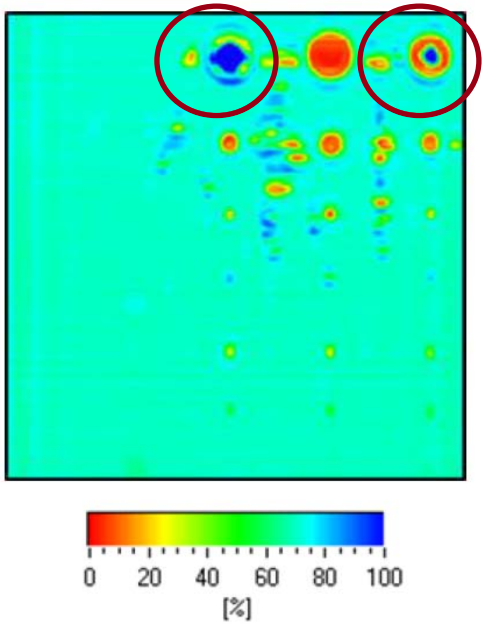


Case study:
Signal increase at some delaminations

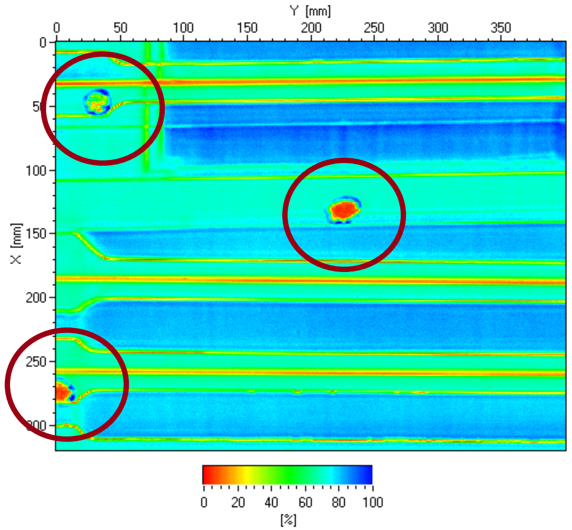
Inserts



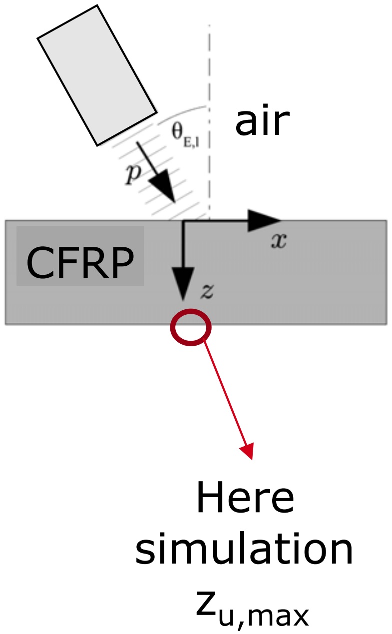
Inserts

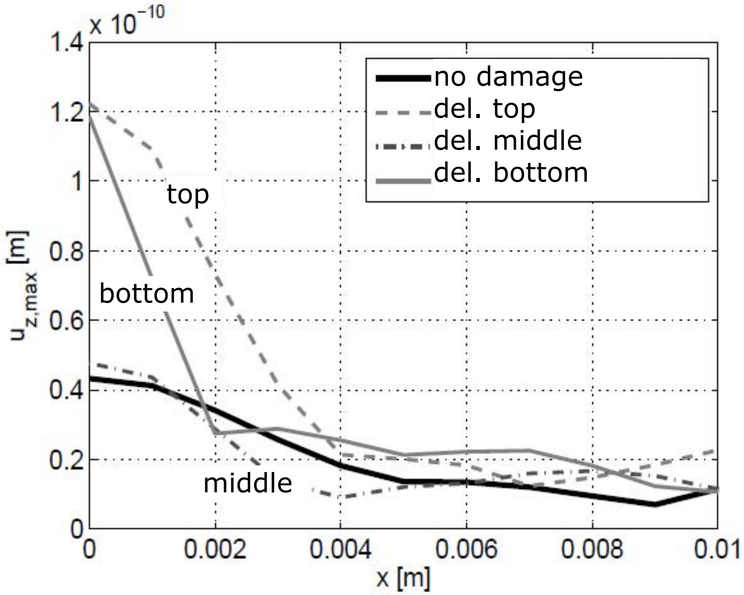


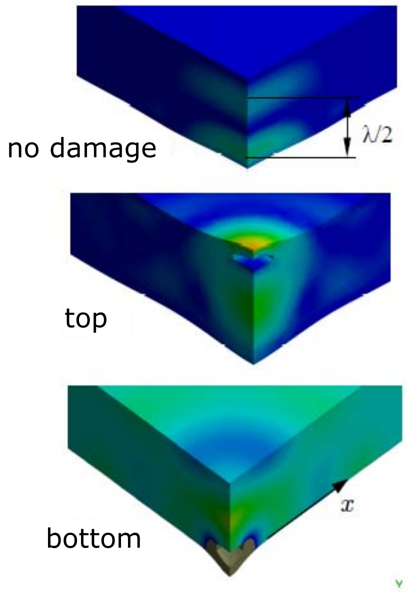
Impact damage



Case study:
Signal increase at some delaminations







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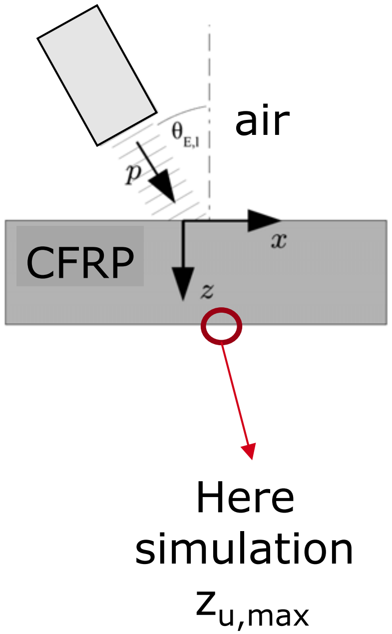
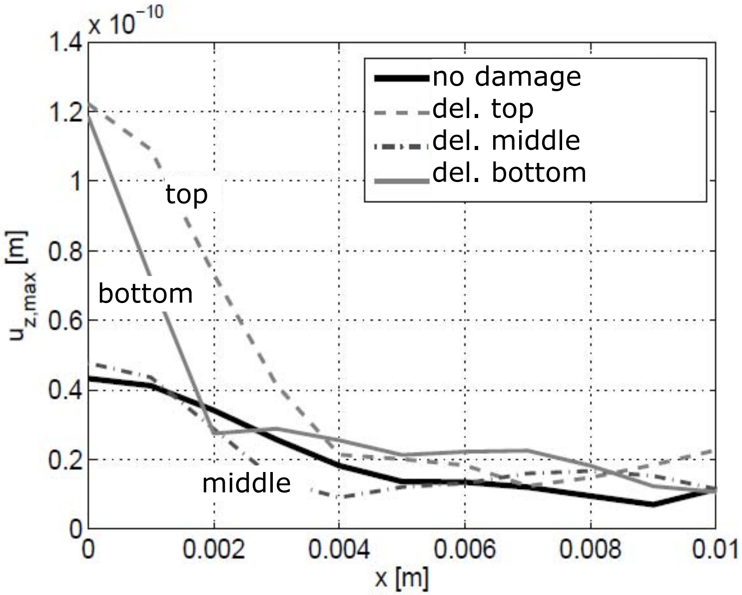
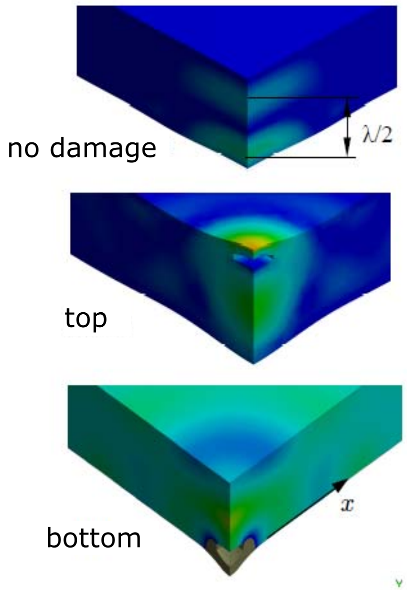
Signal increase at some delaminations







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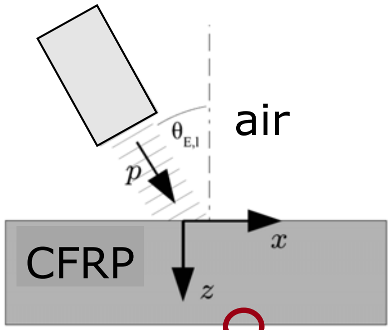
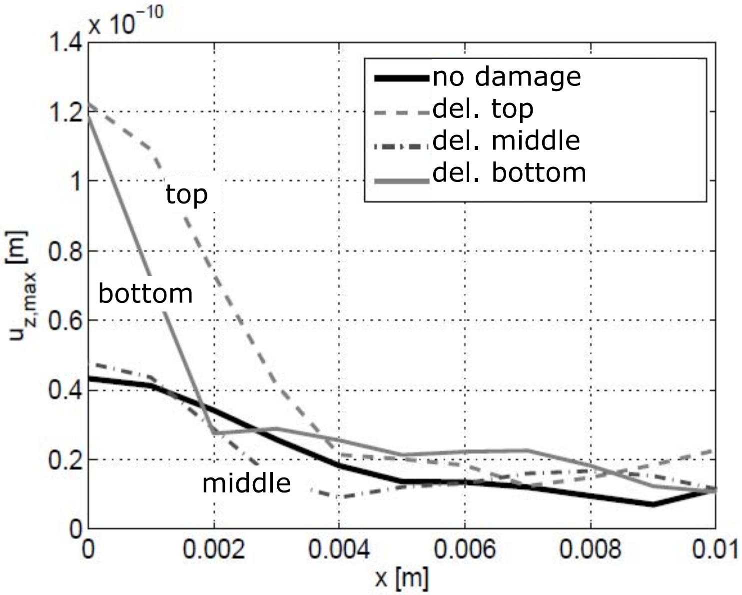
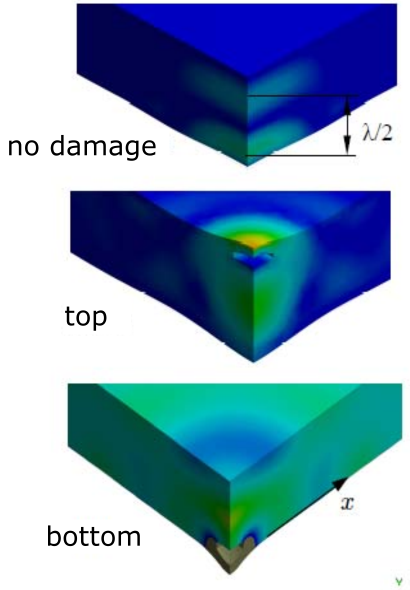
Signal increase at some delaminations



Here simulation $z_{u,max}$





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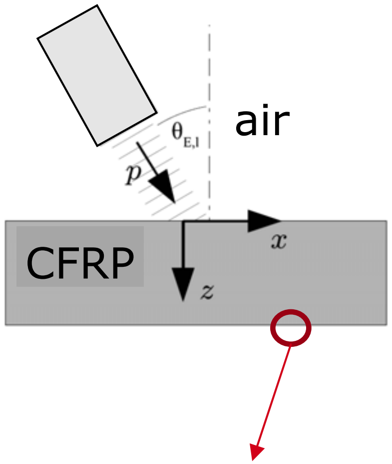
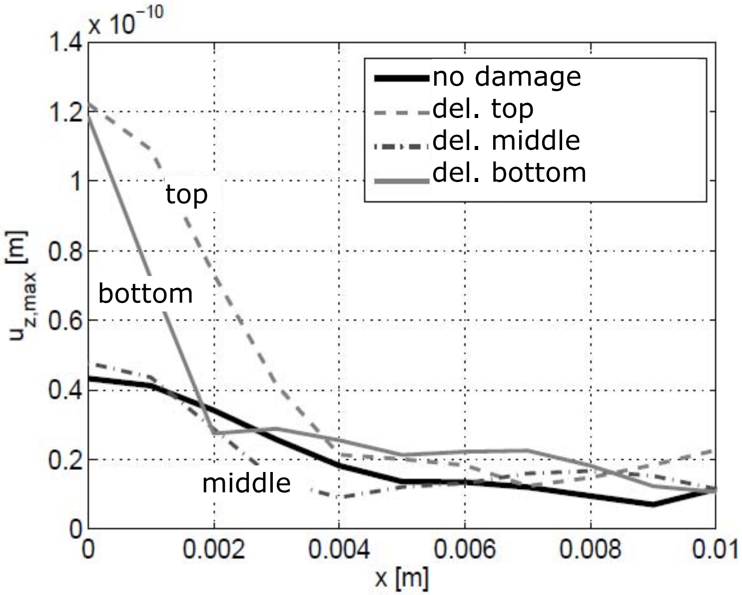
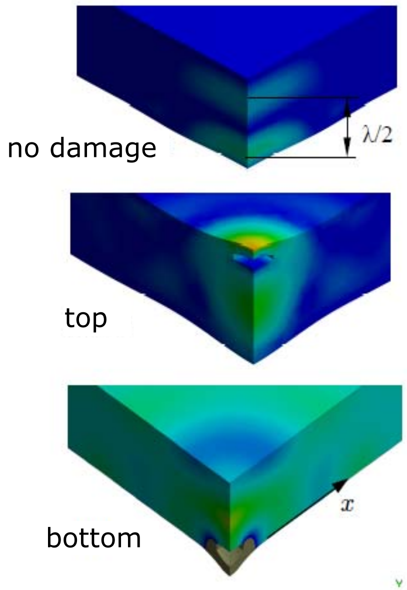
Signal increase at some delaminations



Here
simulation
$z_{u,max}$





Summary and outlook

Summary

FEM tool

- Air-coupled excitation
- Guided waves
- Fiber-reinforced plastic

Results

- Validated on interaction with delaminations
- Air-coupled through transmission of plates allways involves guided waves
- Signal increases on delamination edges

Thank you for your attention!

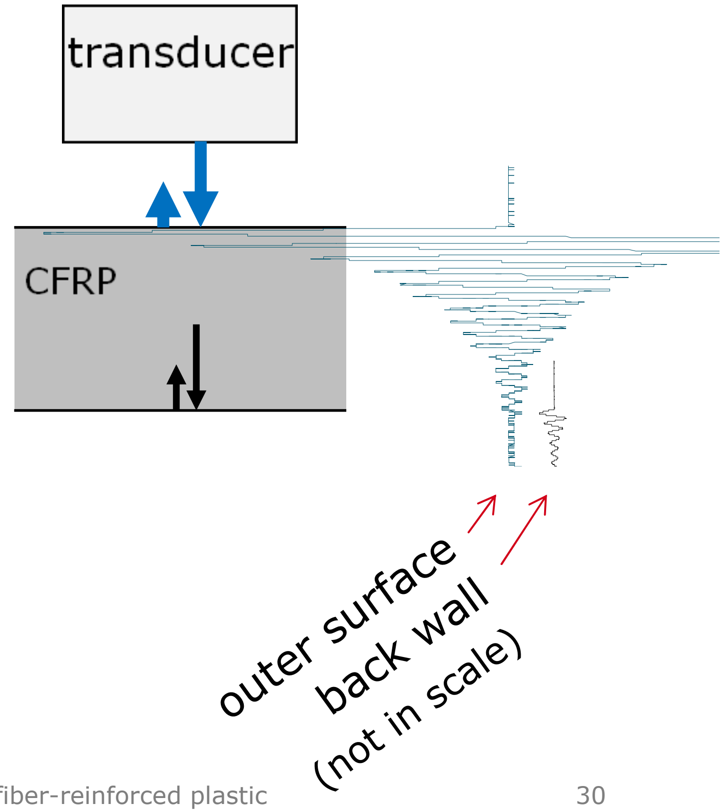
Main challenge of ACUT

Impedance mismatch

- specific acoustic impedance of some materials:
  - air 4.1×10^2 Ns/m^3
  - CFRP 4.5×10^6 Ns/m^3

Pulse-echo practically impossible, very long dead zone

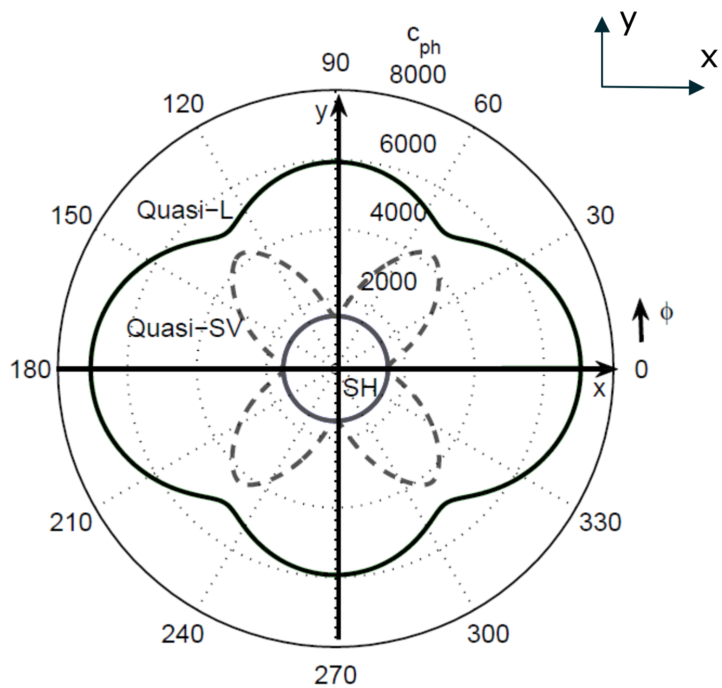
- freq. 250 kHz → λ = 12 mm



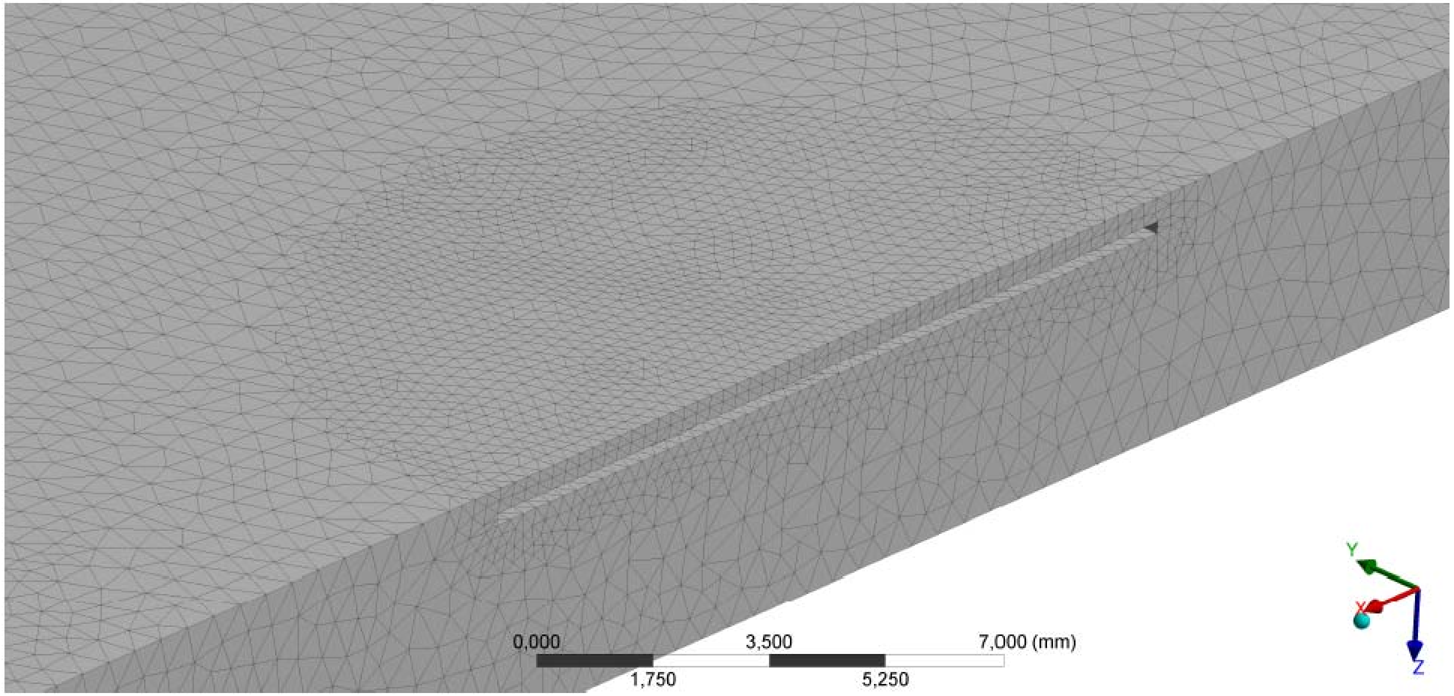
Anisotropy of CFRP with cross-ply laminates

Phase velocities of various GW modes for [0,90]5s

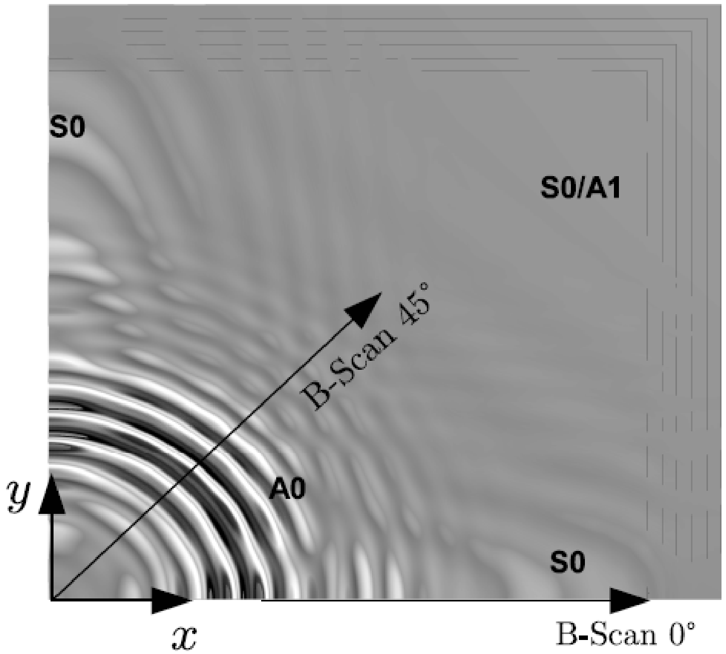
Quasi-L (quasi-longitudinal): S0
Quasi-SV (quasi-shear vertical): A0
Quasi-SH (quasi-shear horizontal)



Mash



Through transmission of cross-ply CFRP

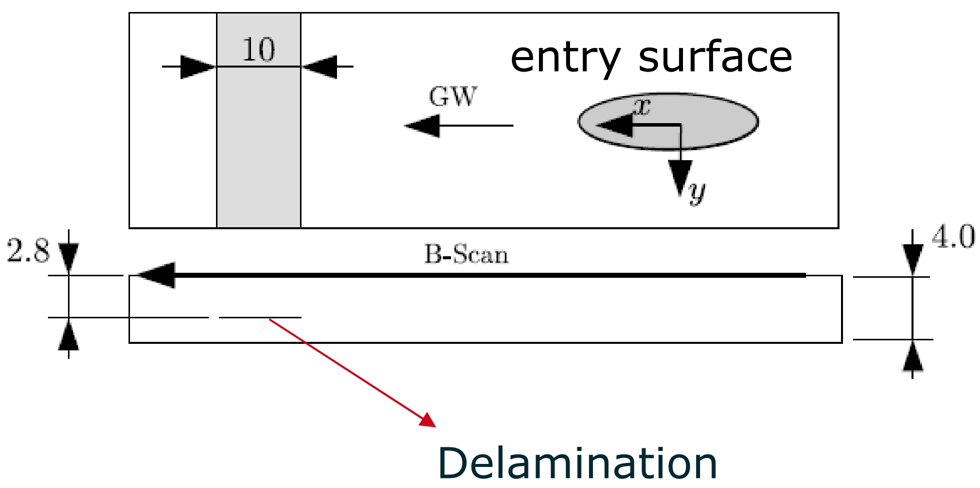


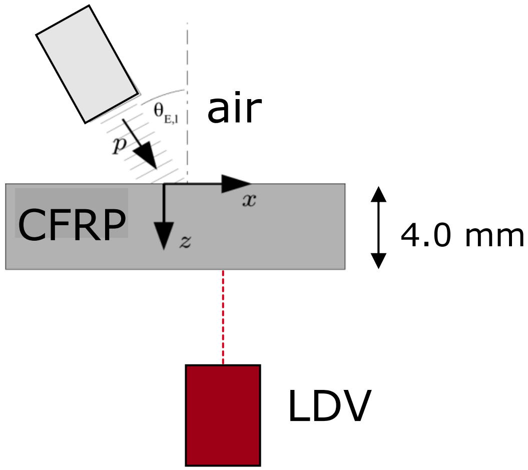
Normal incidence with 270kHz planar transducer

Cross-ply CFRP [0°,90°]5s with thickness ??? mm

3D FEM, snap-shot of the lower side

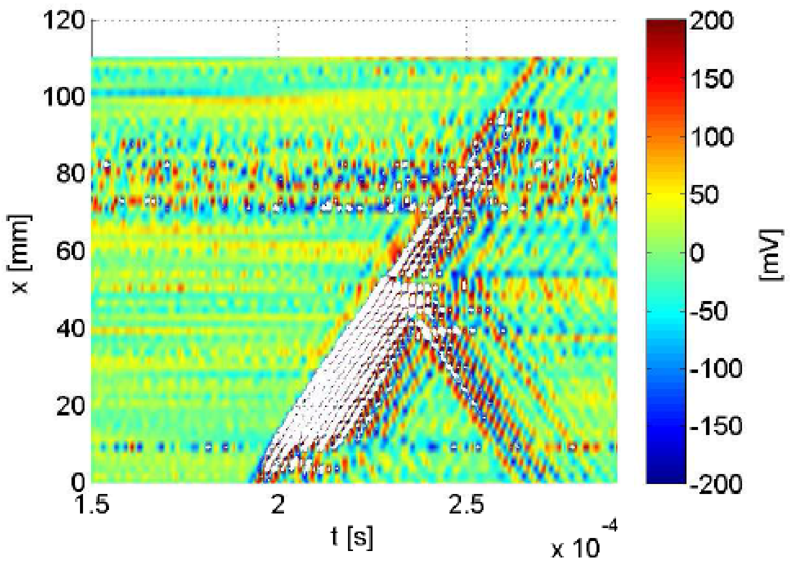
Pitch-catch of cross-ply CFRP





Through transmission of cross-ply CFRP

Measurement with LDV



Simulation (3D FEM)