NDT OF COMPOSITES
@ UGENT-MMS

Prof. dr. ir. Mathias KERSEMANS

WHO ARE WE ?

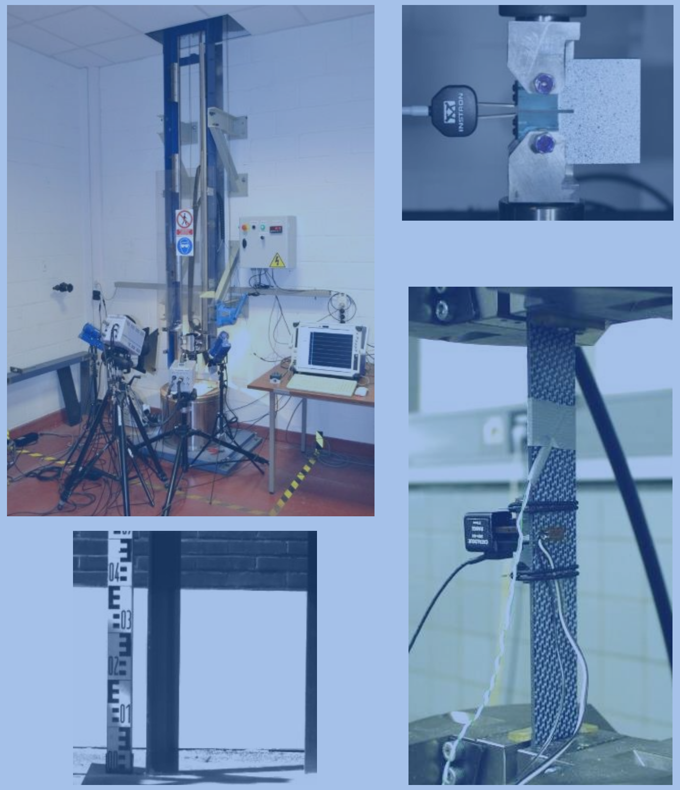
- Research group Mechanics of Materials and Structures

Professors (ZAP)	2 FTE
Business Developer	1 FTE
Assistants (AAP)	1 FTE
Researchers (internal)	29 FTE
Researchers (external)	4 FTE
Spin-offs	4

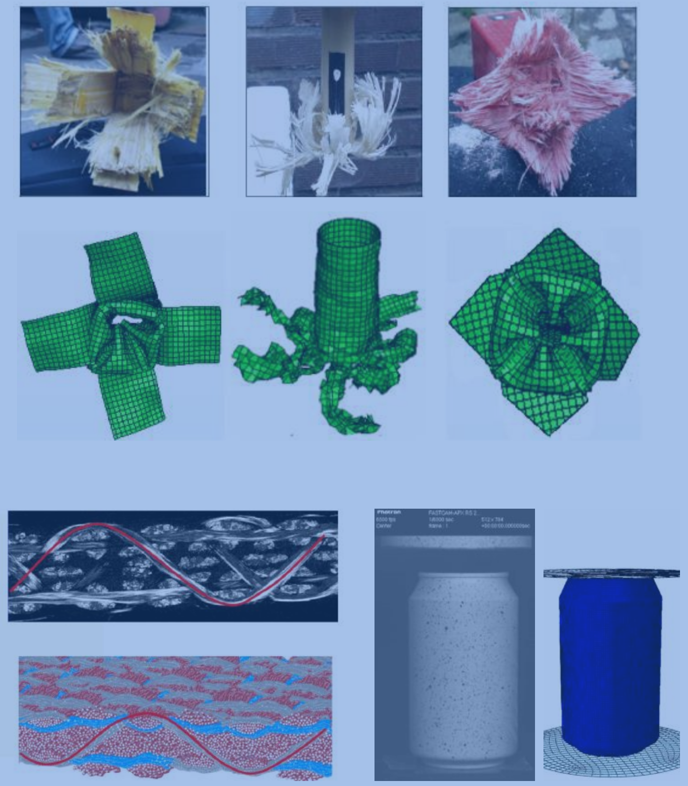
- Experimental and numerical investigations
- Academic and industrial research
- Strong focus on **fiber reinforced plastics** and **3D printed materials**

3 MAIN RESEARCH LINES

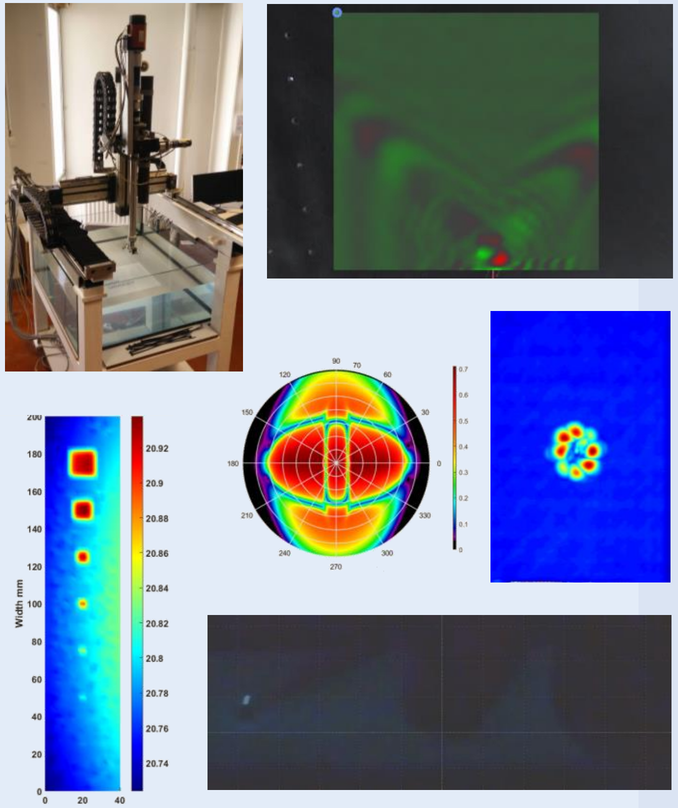
Experimental testing



Numerical modeling



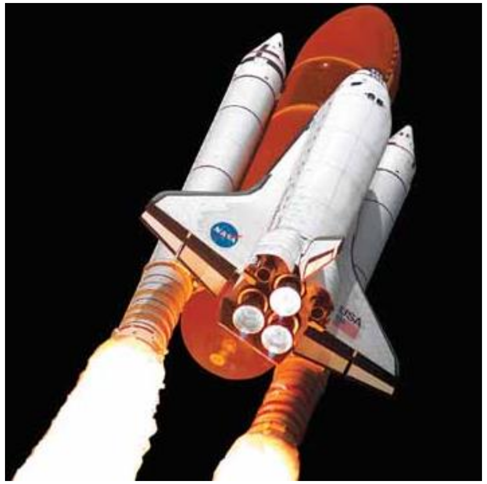
NDT



FIBER REINFORCED PLASTICS

Materials of the present and the future ...

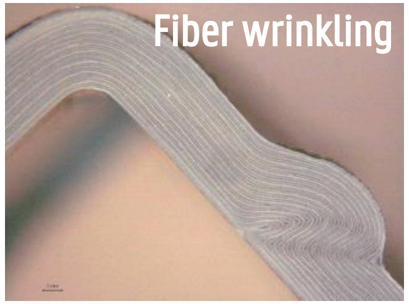
- High specific stiffness and strength
- Large design freedom
- Used in many high-end applications

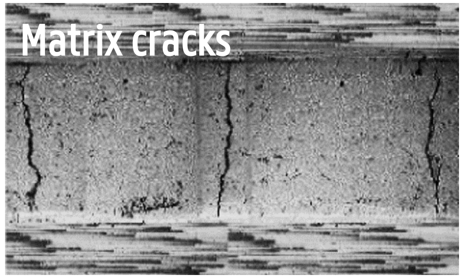


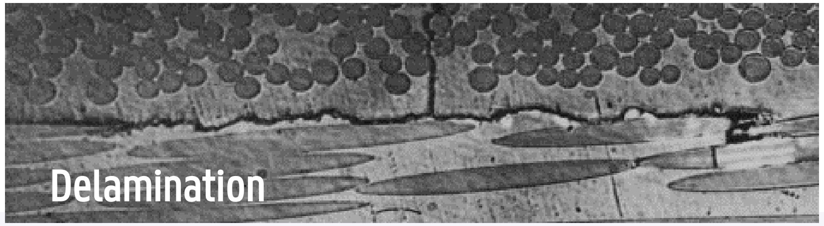
FIBER REINFORCED PLASTICS

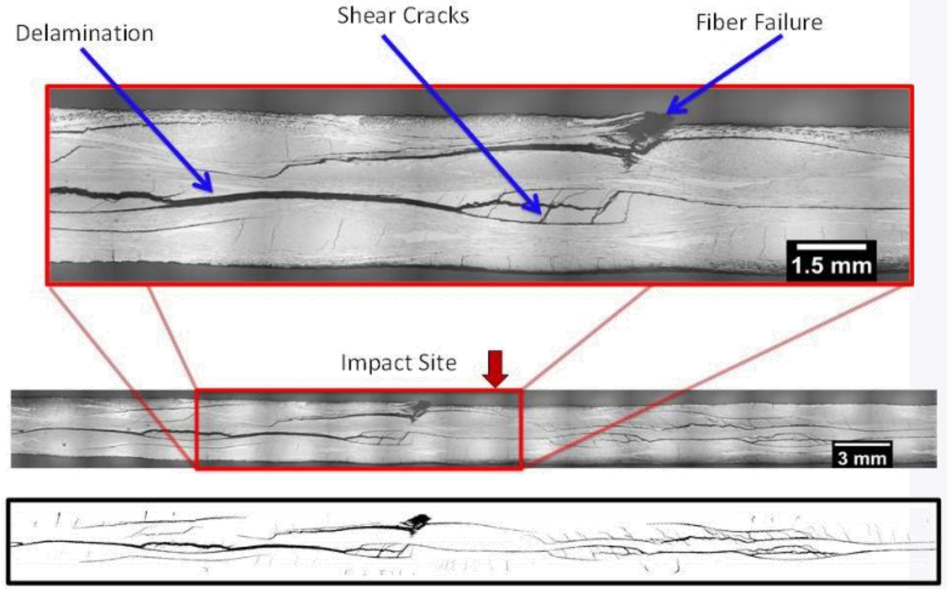
… but very **complex** mechanical behavior
and susceptible to **(internal) defects** …

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$







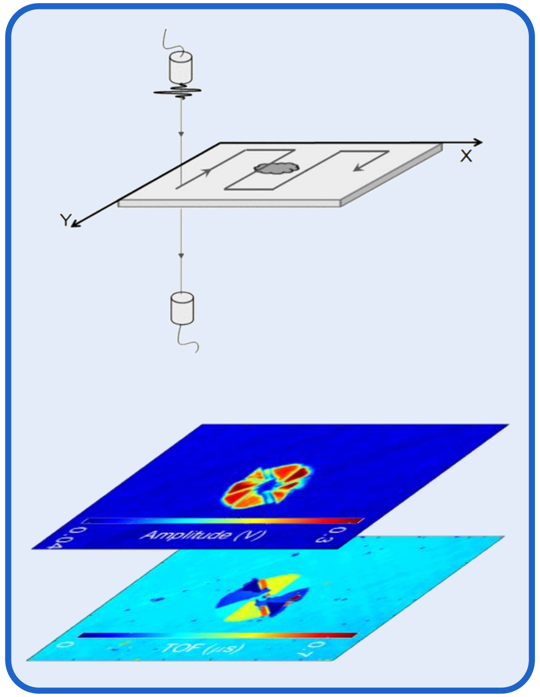


Source: Kevin R. Hart

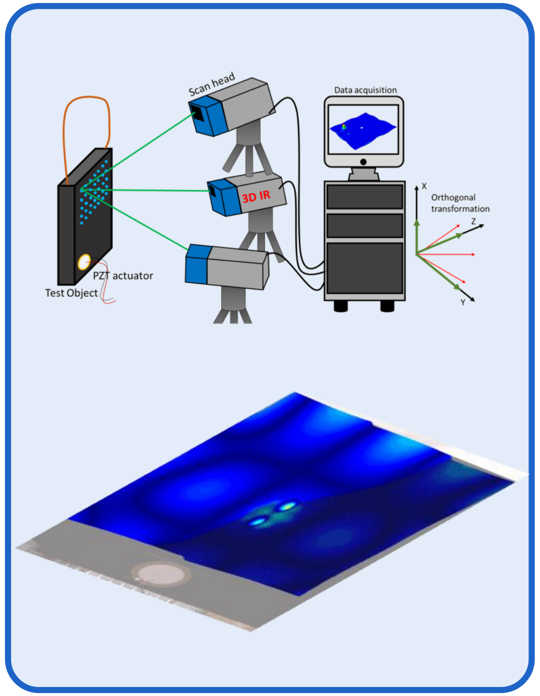
NON-DESTRUCTIVE TESTING

- Need for novel and **innovative NDT** approaches
- A single all-inclusive NDT method does not exist !
- **Fusion** of data

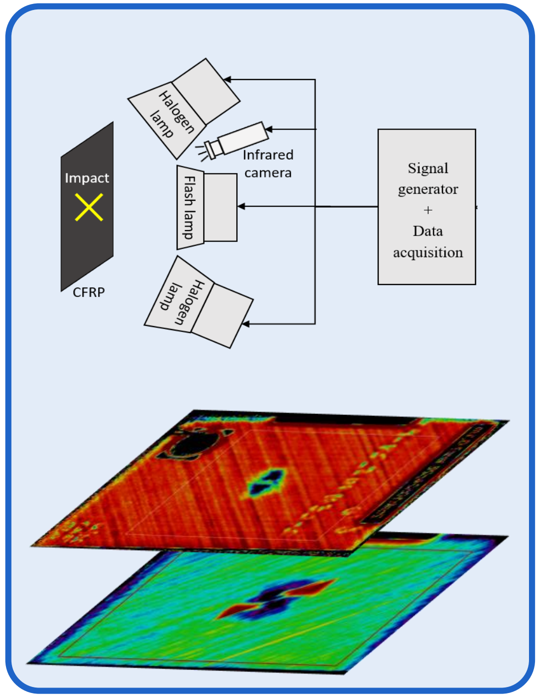
I. ULTRASOUND



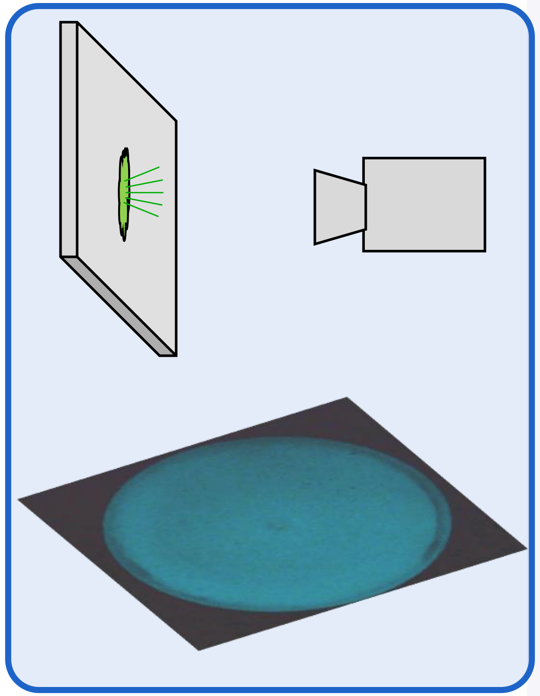
II. VIBROMETRY

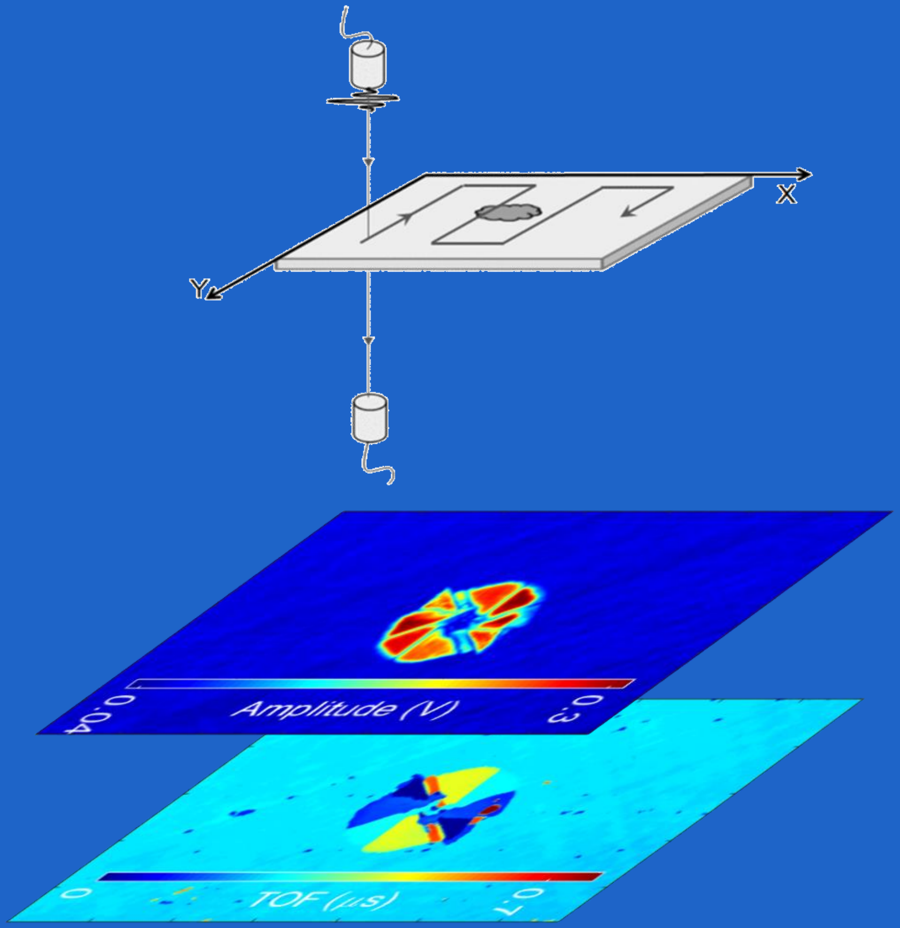


III. THERMOGRAPHY



IV. LUMINESCENCE





I. ULTRASOUND

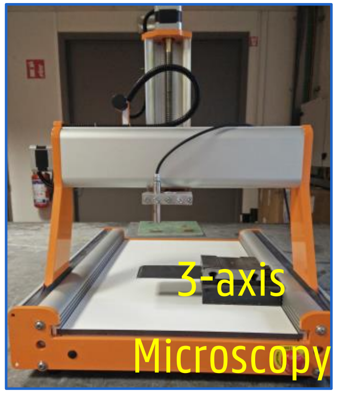
ULTRASOUND – EQUIPMENT

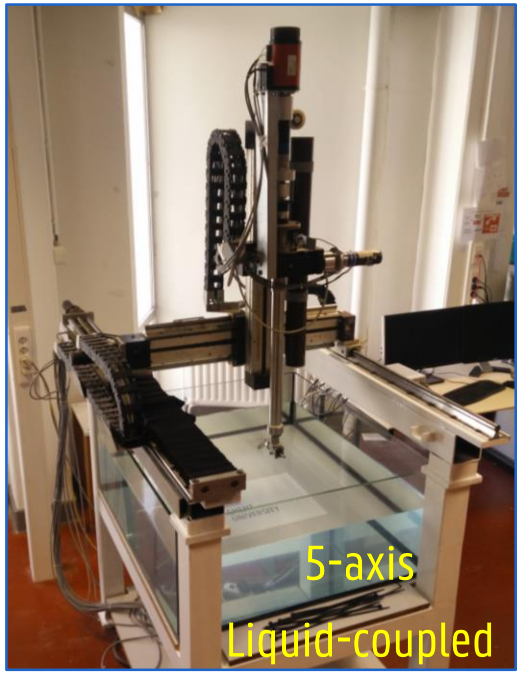
In-house developed ultrasonic scan inspection facilities

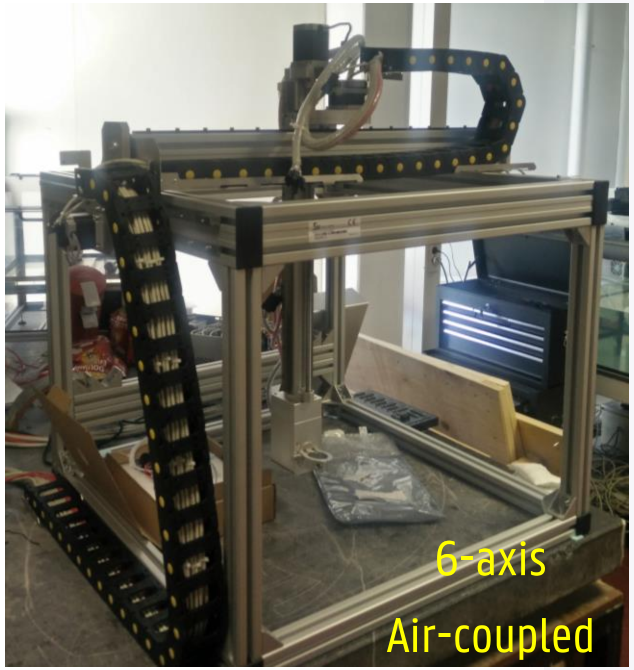
- 3-, 5- and 6-axis scanners
- Fully programmable → complete freedom in scan strategies
- Various ultrasound regimes available
  - Conventional liquid-coupled ultrasound
  - Phased array ultrasound
  - Ultrasonic microscopy (up to 100 MHz)
  - Air-coupled ultrasound

PXIe

PHASED ARRAY



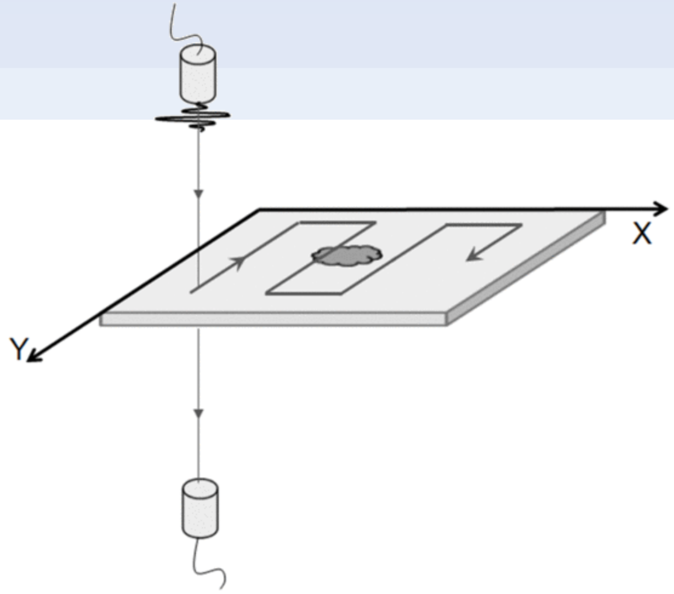




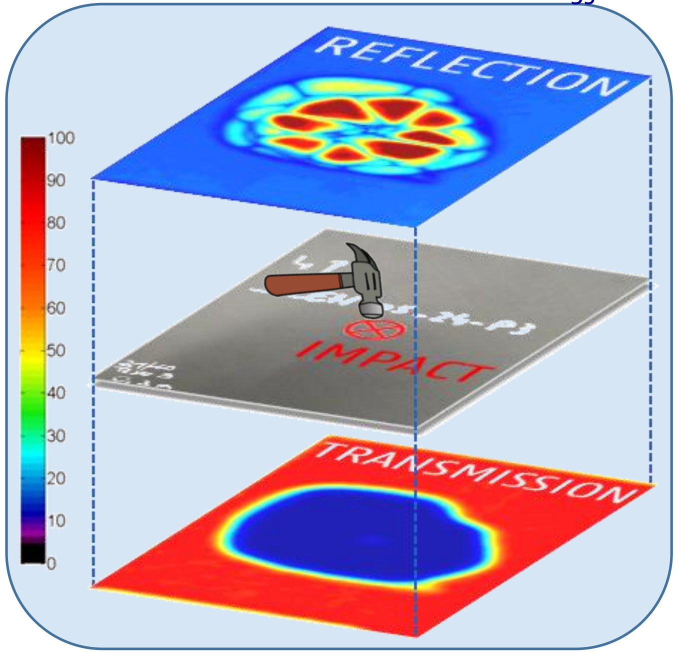
ABCD-scan

- Surface scan
- Liquid-coupled
- Used in industry (in its most basic form)
- Blueprint of damage features:

- ✓ Delaminations
- ✓ Cracks
- ✓ Inclusions
- ✓ Debonding



EXAMPLE: IMPACTED $[45/0/-45/90]_{3S}$ C/E



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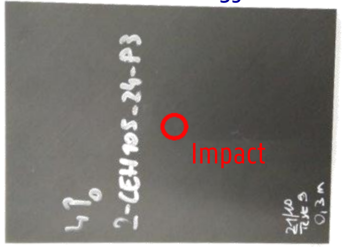
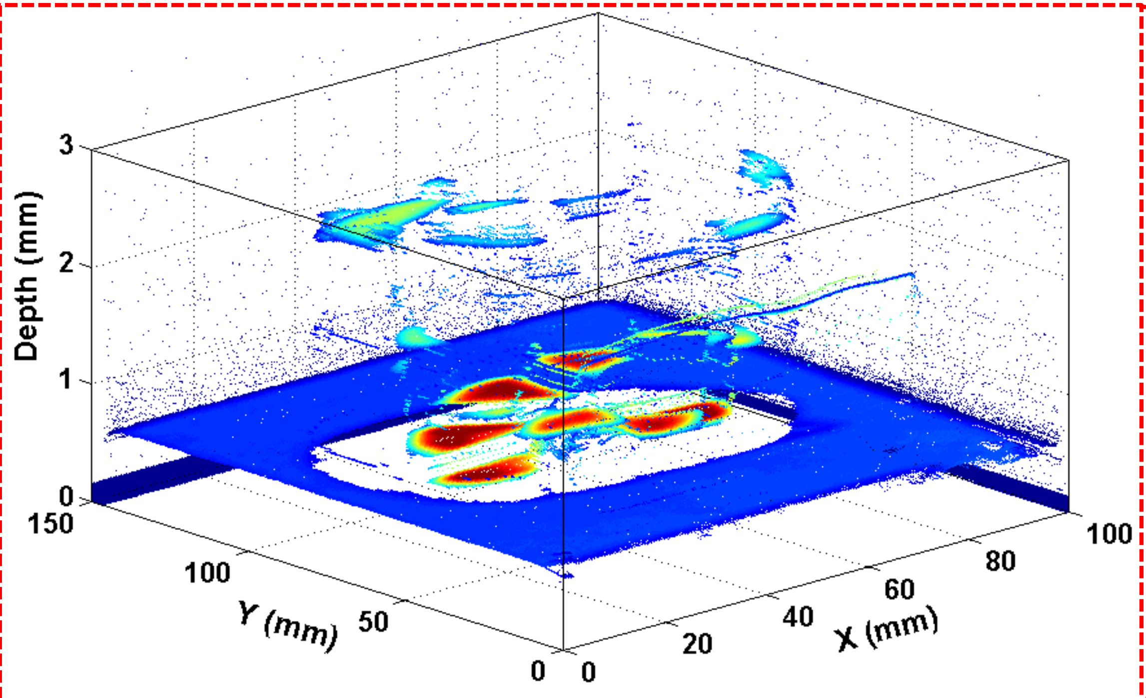
ULTRASOUND – ABCD SCAN

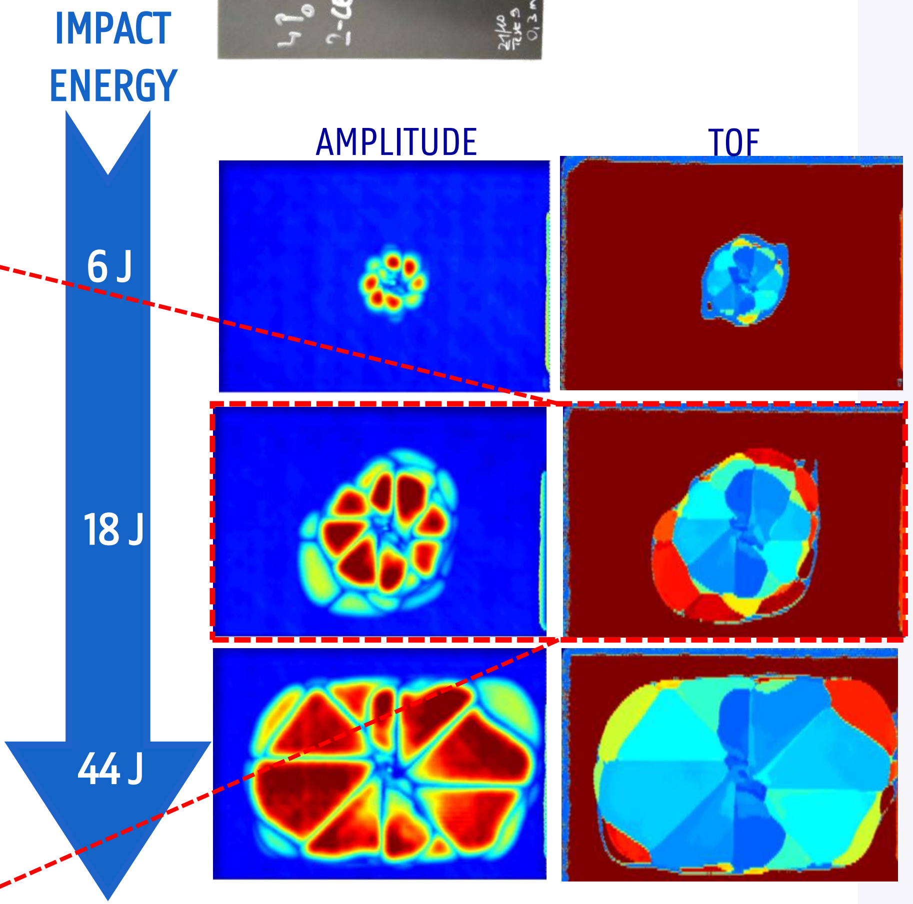
- Impacted CFRP with Barely Visible Impact Damage BVID
- Depth resolved defect imaging
- Recently upgraded with **air-coupled ultrasound**

$[45/0/-45/90]_{3S}$ CFRP



3D view of impact damage





In close collaboration with lab of Koen VAN DEN ABEELE & Steven DELRUE (KULAK)

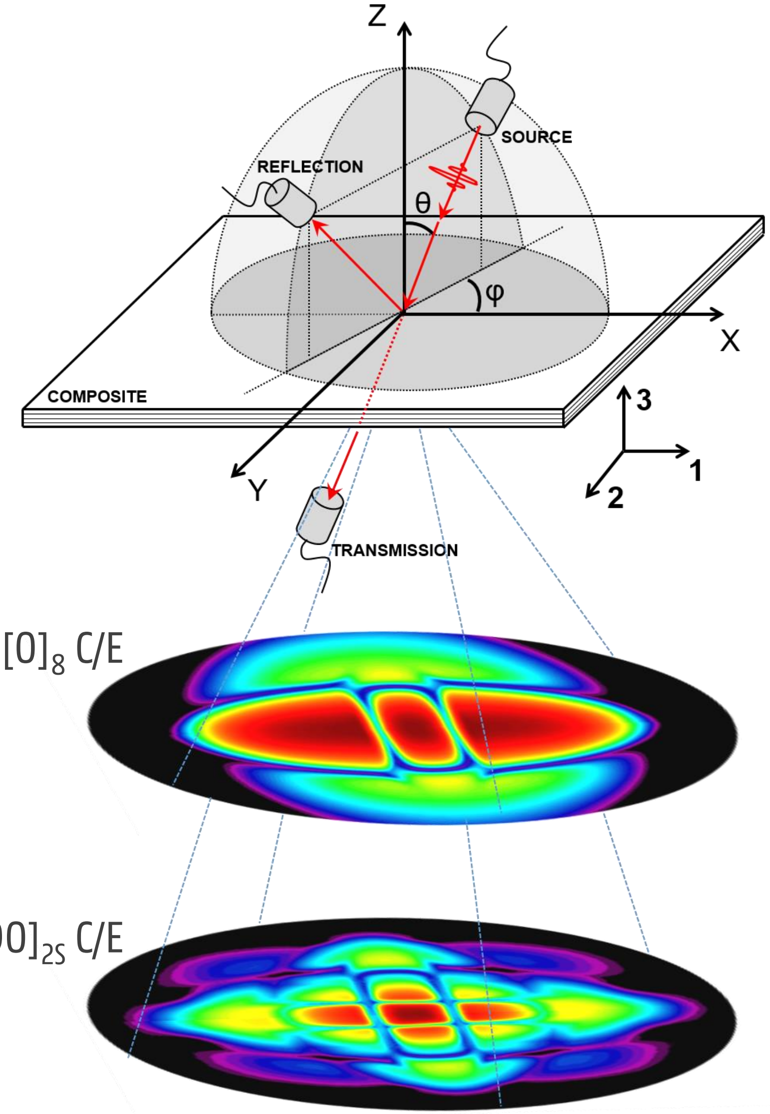
Ultrasonic Polar Scan (UPS)

- φθ-scan
- Water-coupled
- Fingerprint of orthotropic material properties

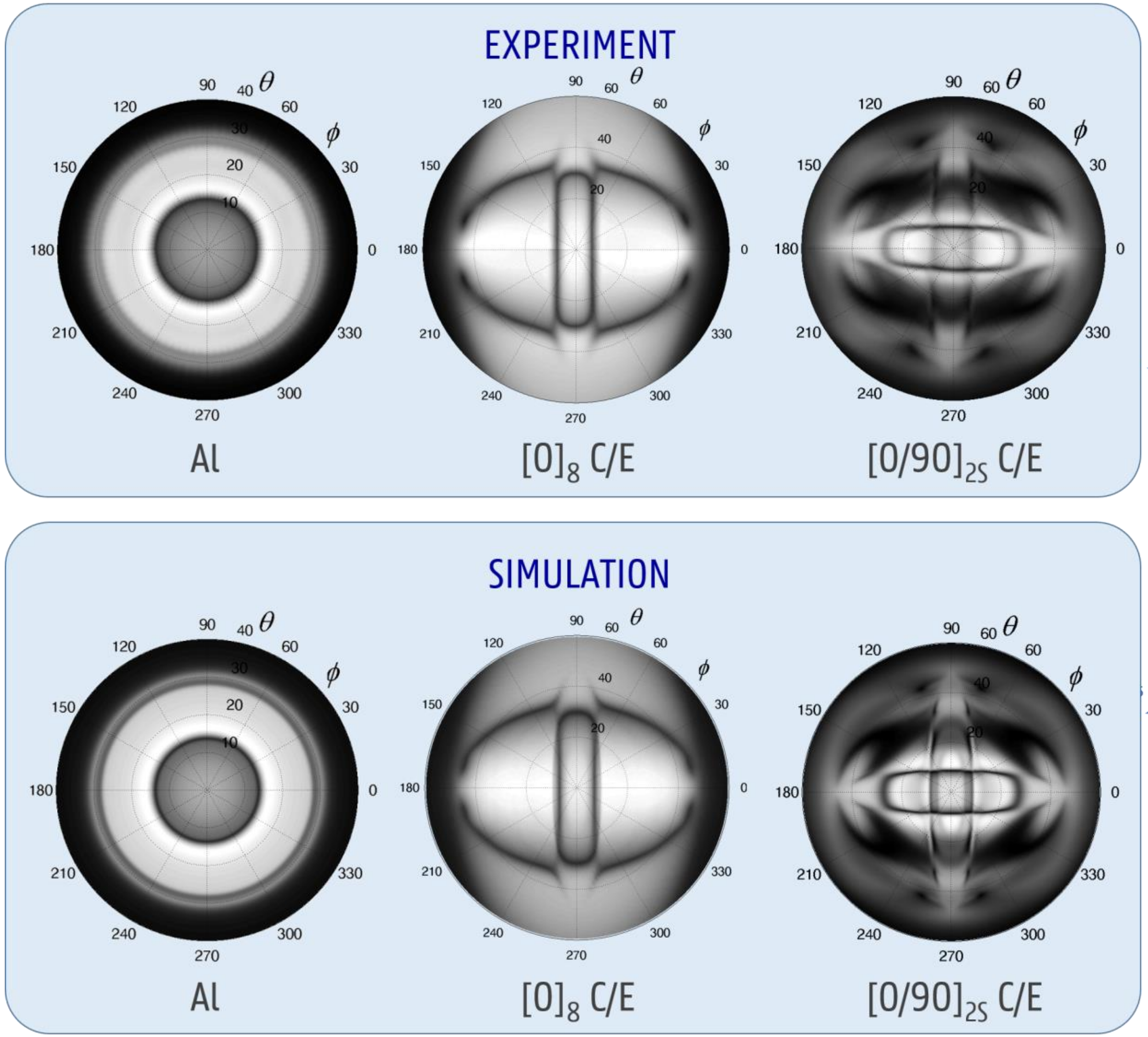
✓ Elastic tensor

✓ Viscous tensor

✓ Strain tensor



In close collaboration with lab of Koen VAN DEN ABEELE & Steven DELRUE (KULAK)

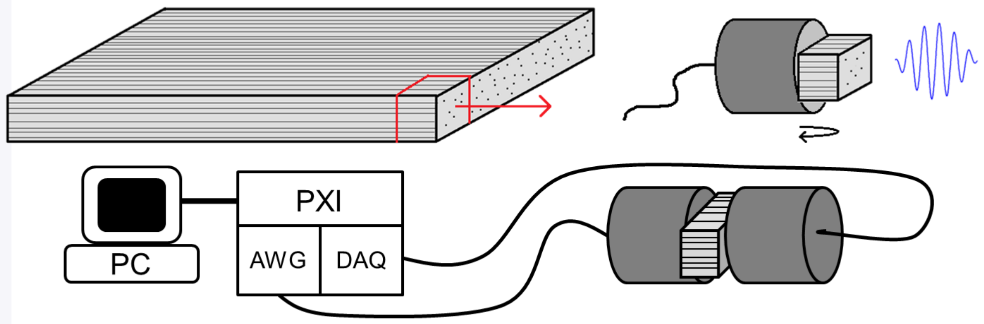


Fingerprint of orthotropic visco-elasticity

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$

ULTRASOUND – VARIOUS

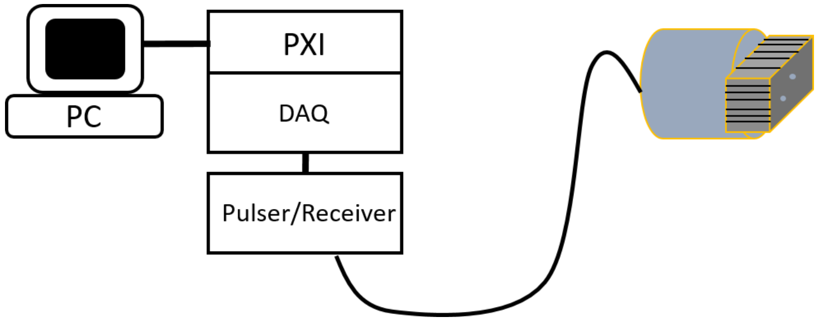
Contact ultrasound to determine stiffness tensor

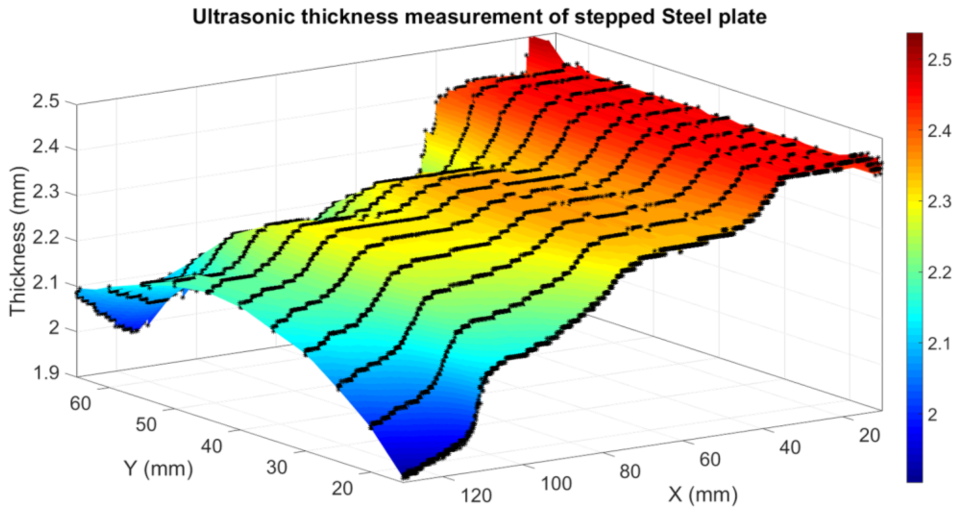


Elastic properties of PA-12, measured ultrasonically.

E_{11}	2167.4 ± 20 MPa
E_{22}	2156.7 ± 9 MPa
E_{33}	2209.4 ± 36 MPa
ν_{12}	0.4039 ± 0.0128
ν_{13}	0.3785 ± 0.0151
ν_{23}	0.3786 ± 0.0037
G_{12}	771.3 ± 2 MPa
G_{13}	779.2 ± 16 MPa
G_{23}	770.3 ± 1 MPa

Ultrasound to determine (coating) thickness with µm resolution





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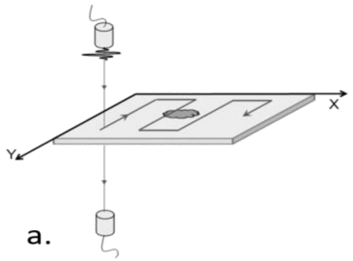
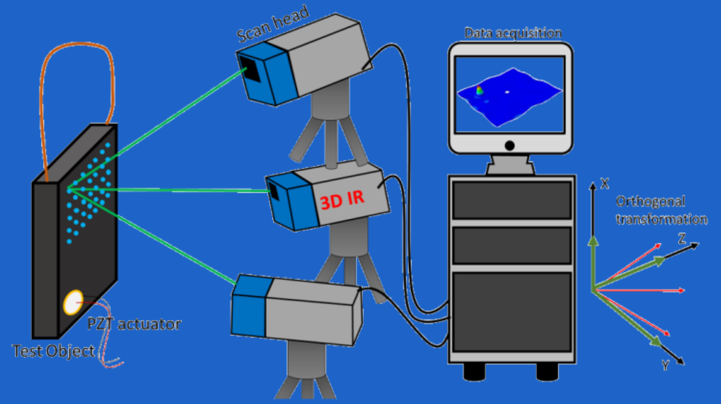
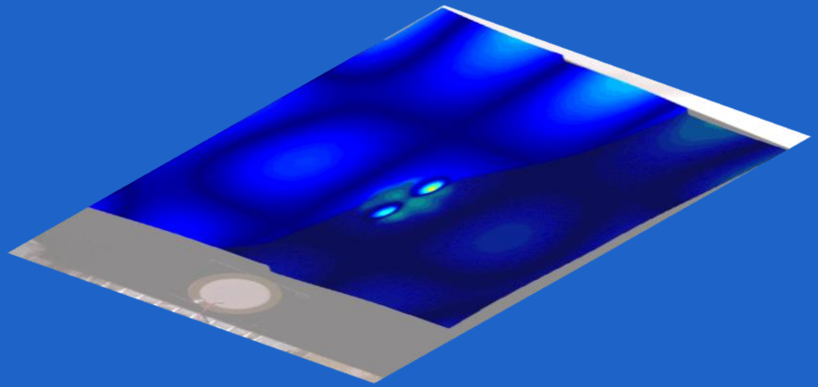
ULTRASOUND



	Ultrasound
Defect detection	+++
Defect sizing	+++
Depth estimation	+++
Material characterization	+++
Inspection time	-
Contactless	0
Complex geometry	-
Cost	-

Air-coupled ultrasound !





II. VIBROMETRY

VIBROMETRY – EQUIPMENT

High-end 3D Infrared Scanning Laser Doppler Vibrometer

- 3 measurement lasers → **XYZ vibrational data**
- **Infrared lasers** → optimal reflectivity on CFRP
- **Scanning** complex structures
- Bandwidth: 0-25 MHz
- Sensitivity < 0.000,000,000,001 m (< 1pm) !!!
  (50 million times smaller than human hair!)


Multi-channel DAQ


SHAKER


PZT

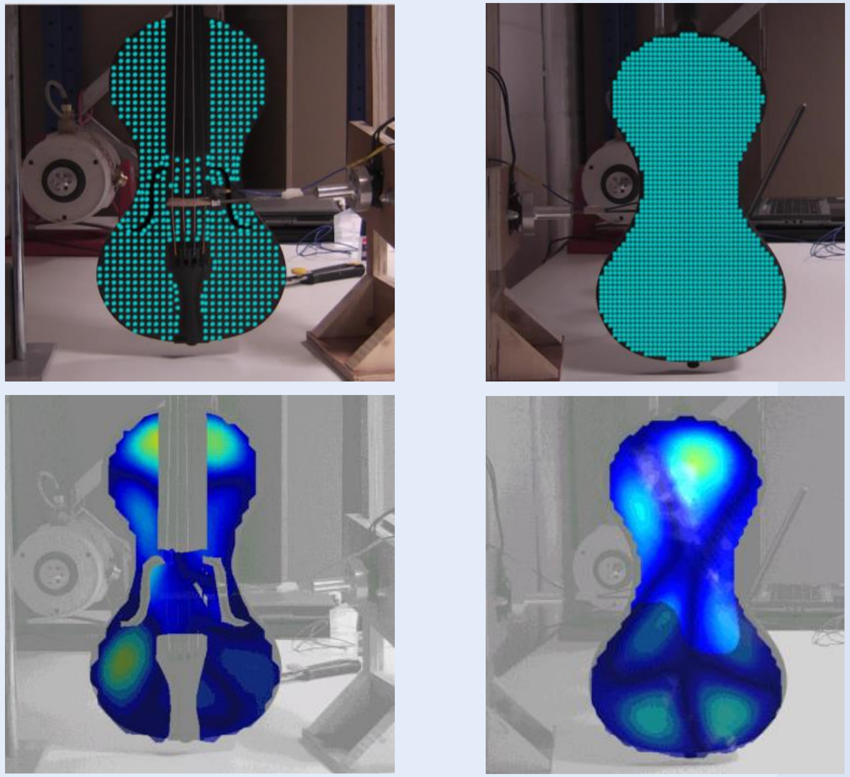
3D IR SLDV

VIBROMETRY – VIOLINS

Modal analysis

- ✓ Measure the vibrational response
- ✓ See the vibrational patterns

Composite violins



f = 1037 Hz

f = 963 Hz

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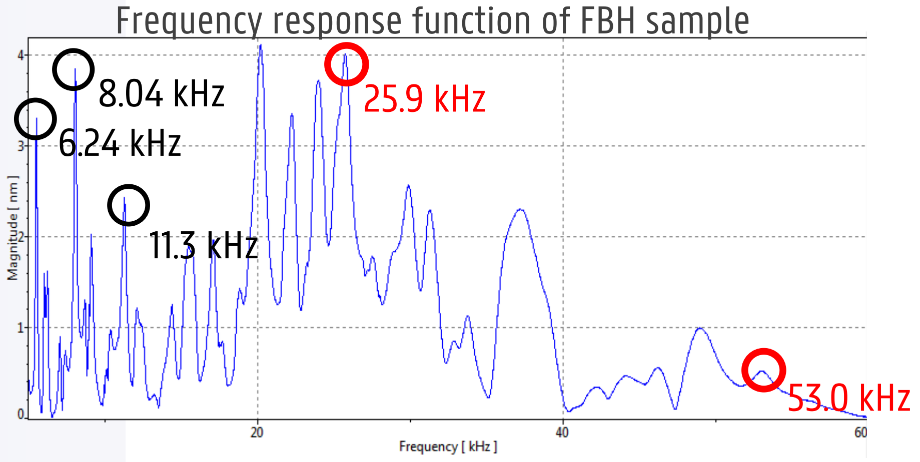
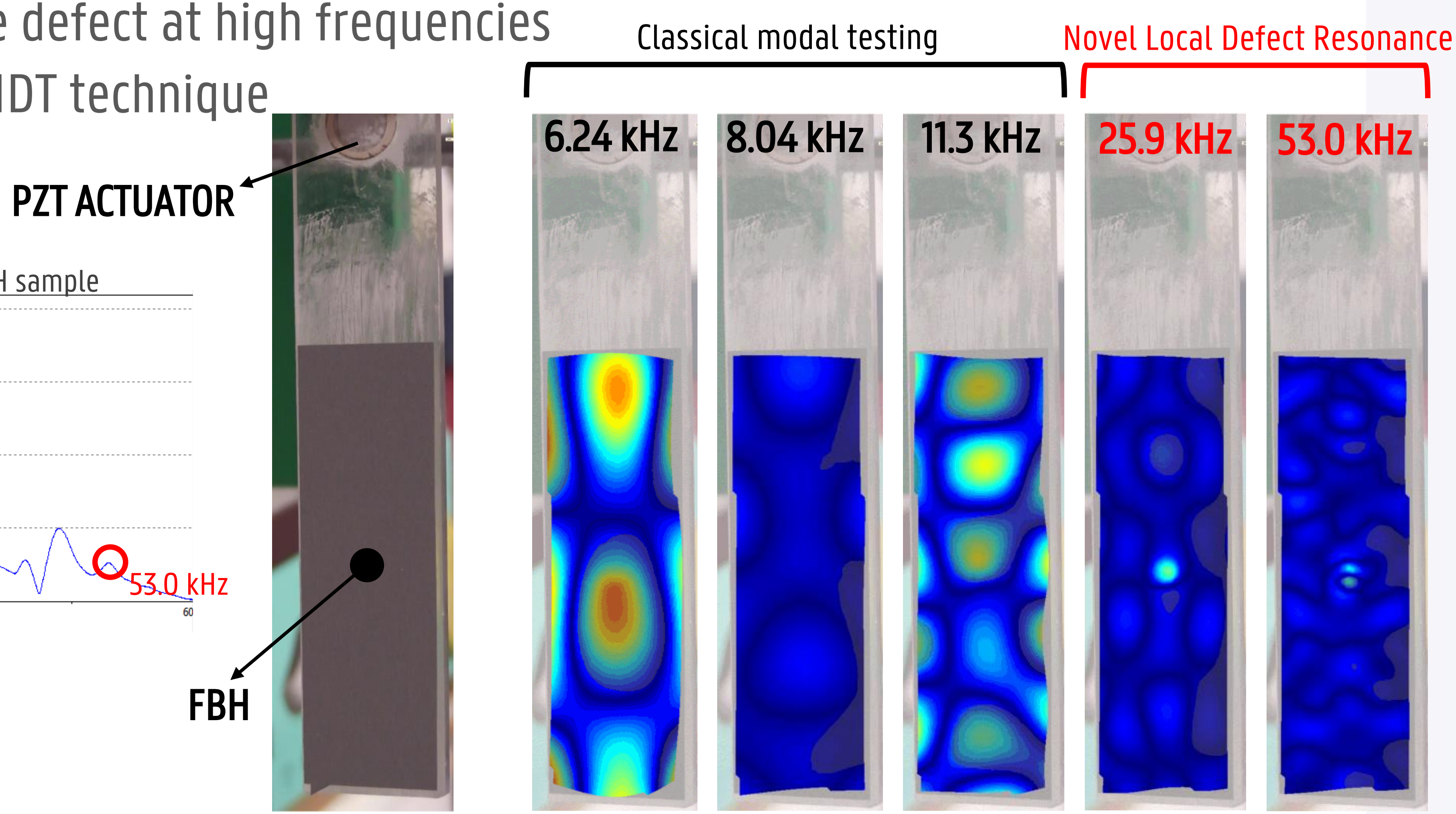
Local Defect Resonance LDR

- ✓ Resonate only the defect at high frequencies
- ✓ Highly sensitive NDT technique





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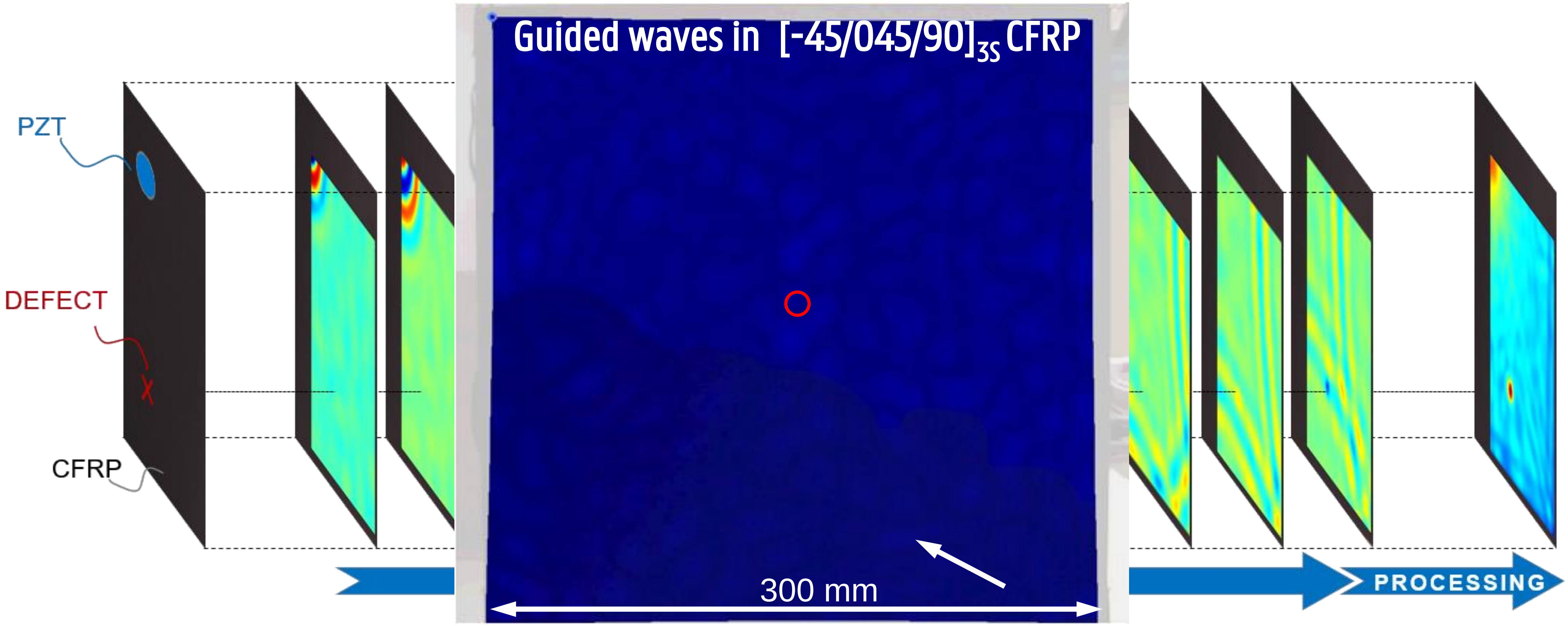
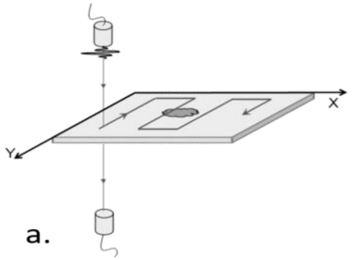
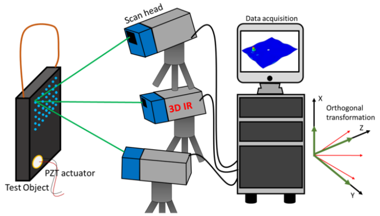
VIBROMETRY – GUIDED WAVES

Guided wave propagation

- ✓ Defect detection and assessment
- ✓ Material characterization



VIBROMETRY

	 Ultrasound	 Vibrometry
Defect detection	+++	++
Defect sizing	+++	+
Depth estimation	+++	0
Material characterization	+++	++
Inspection time	-	++
Contactless	0	+++
Complex geometry	-	++
Cost	-	-

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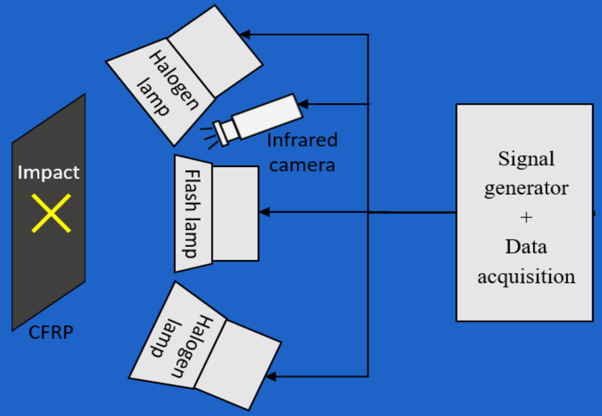

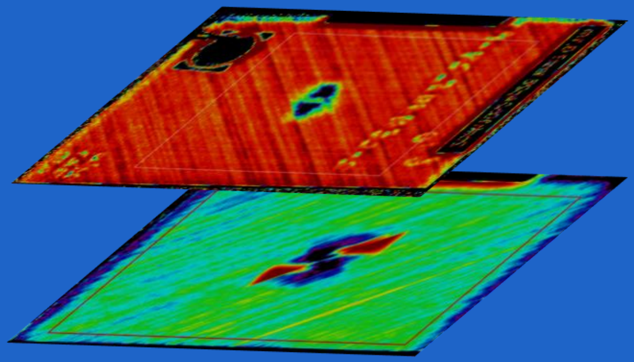

III. THERMOGRAPHY

THERMOGRAPHY – EQUIPMENT

Advanced infrared thermographic system

- Cooled infrared camera FLIR A6750sc
- Pixel density = 640 x 512 → full field technique
- NETD < 15 mK
- High-standard control module
- Various thermography regimes

PZT – Vibrations

HALOGEN LAMPS

HIGH-POWER FLASH LAMP

CONTROL MODULES

IR THERMOGRAPHIC SYSTEM

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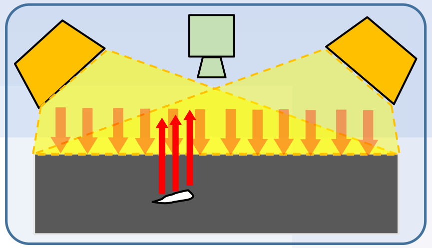
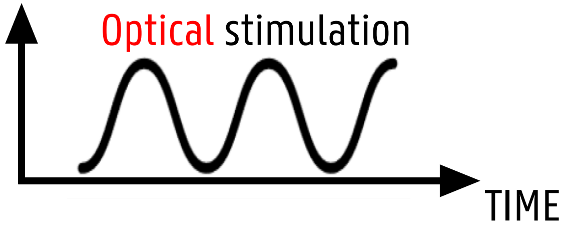
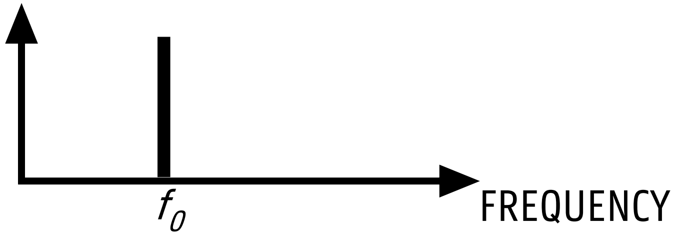


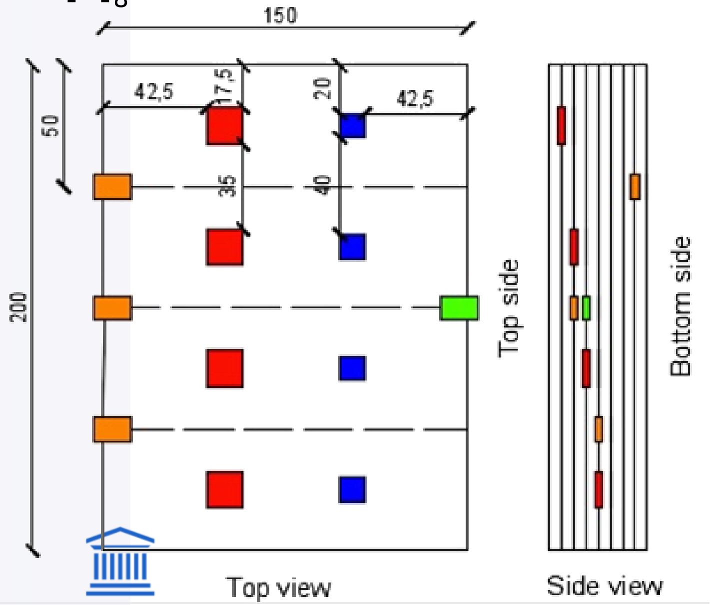
Lockin thermography: Sinusoidal optical heating

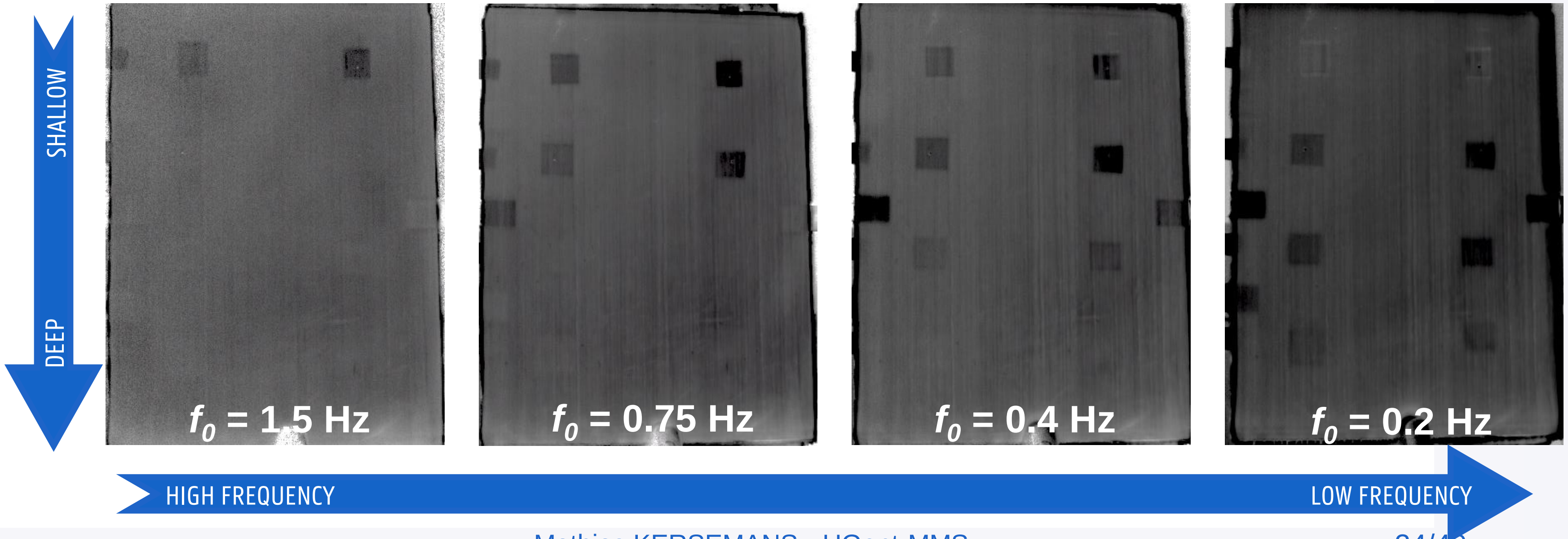




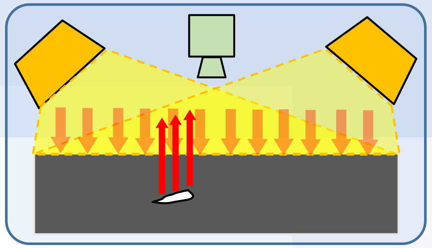
- ✓ High signal-to-noise ratio
- ✓ Poor depth probing

$[0]_8$ CFRP with Teflon inserts

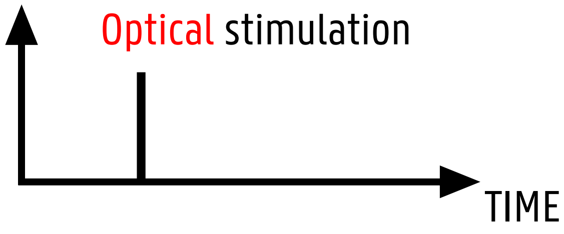


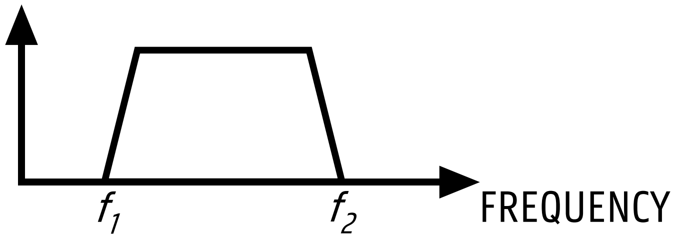


THERMOGRAPHY – FLASH



Flash thermography: Short but intense flash optical heating

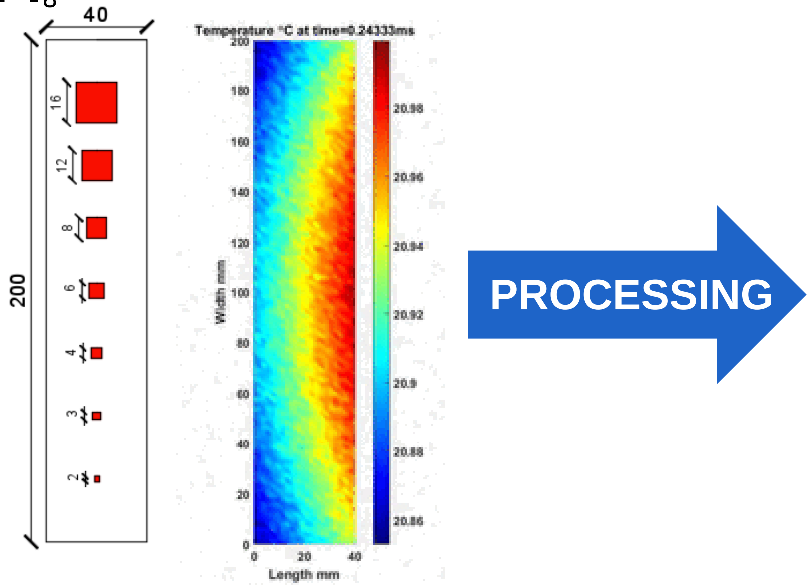


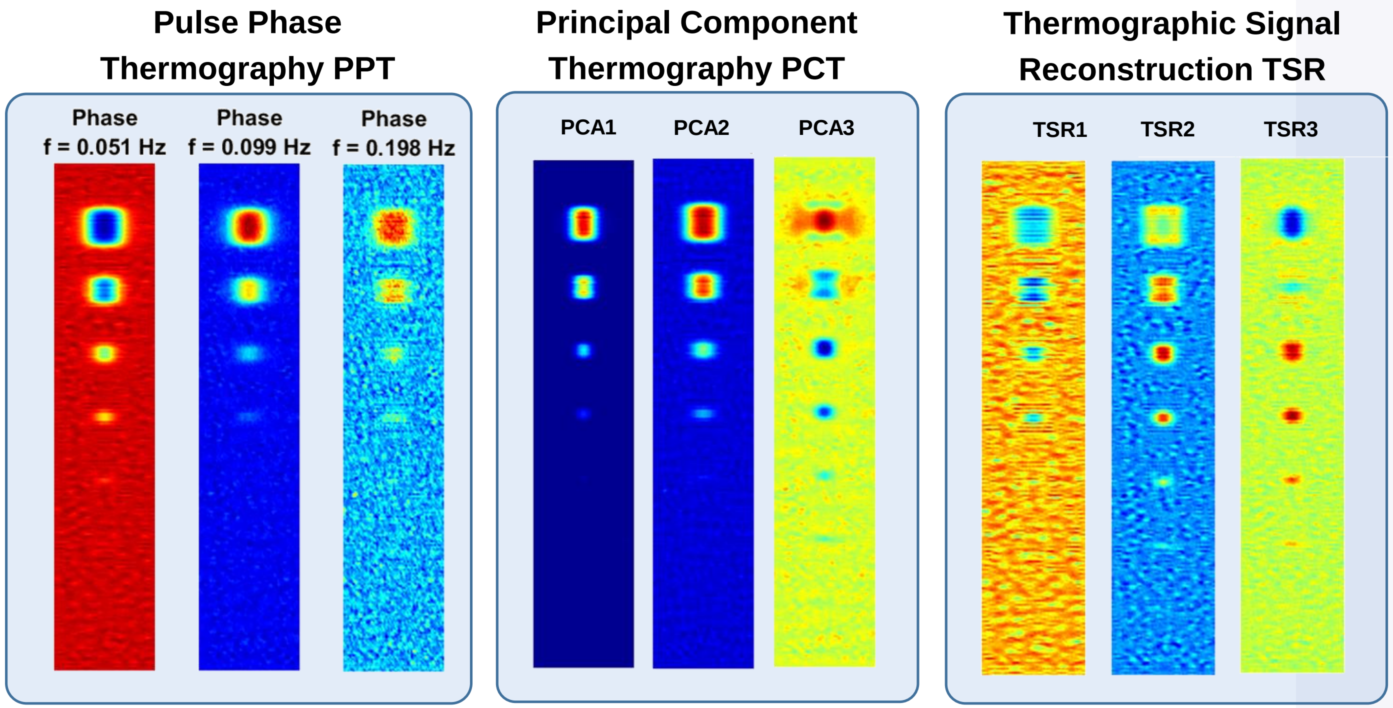


✓ Low signal-to-noise ratio

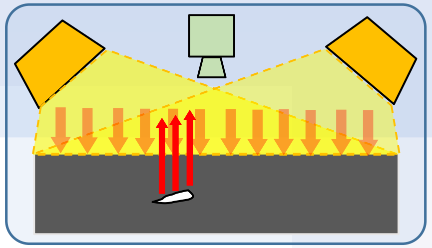
✓ Good depth probing

$[0]_8$ CFRP with Teflon inserts

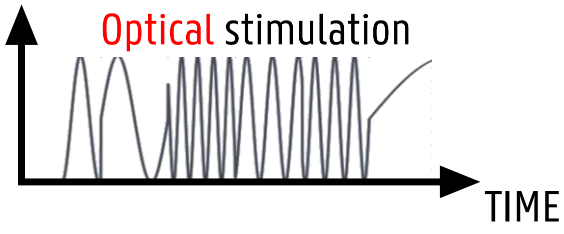


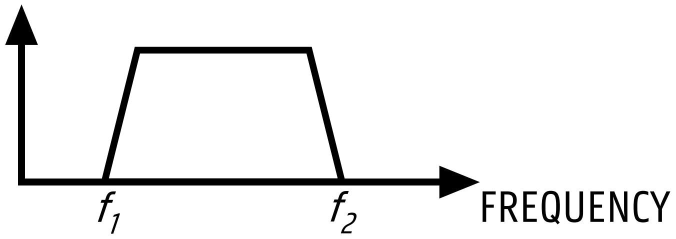


THERMOGRAPHY – THERMAL WAVE RADAR

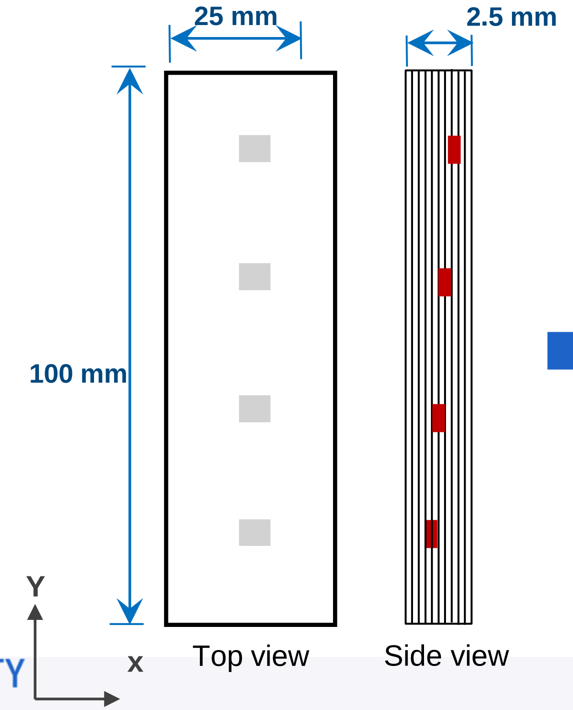


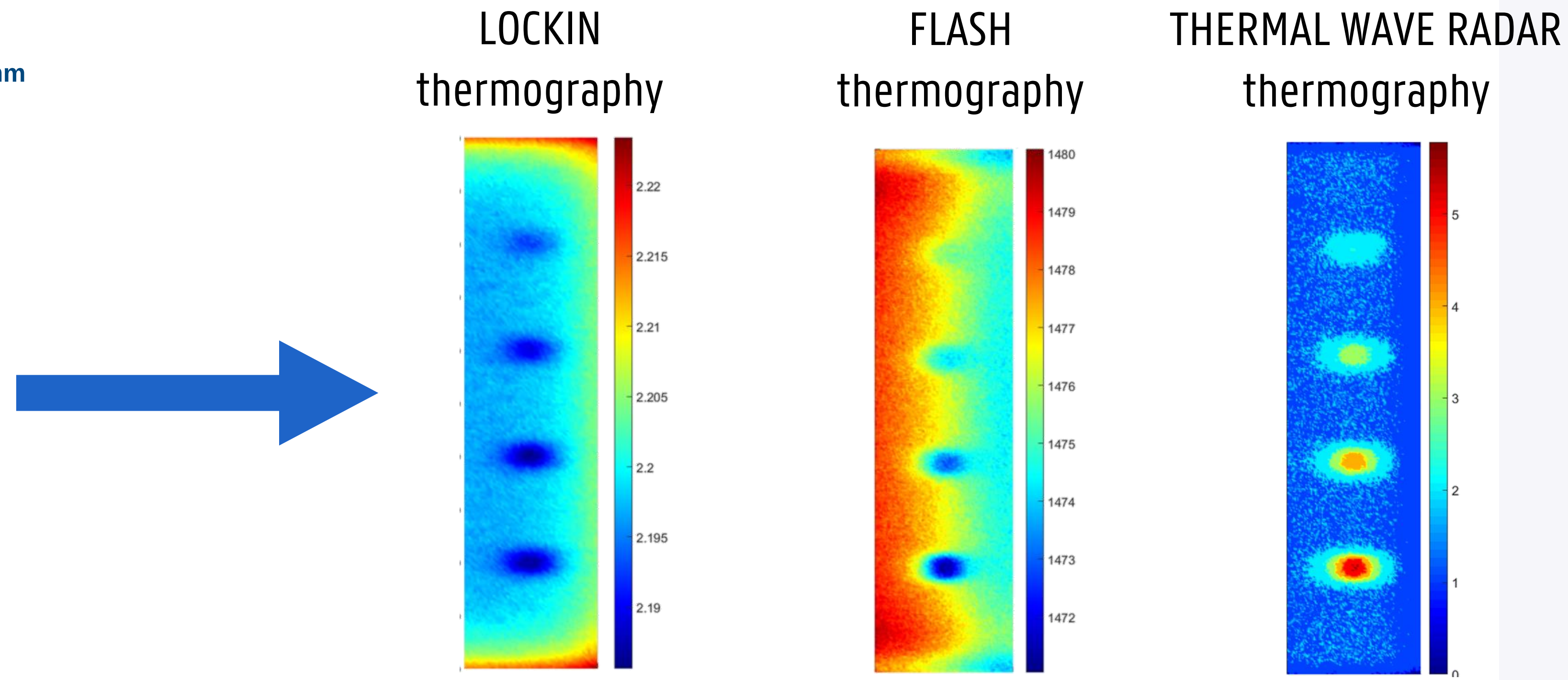
Thermal wave radar thermography: Complex coded optical heating





- ✓ High signal-to-noise ratio
- ✓ Good depth probing





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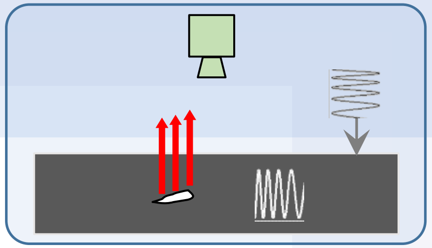
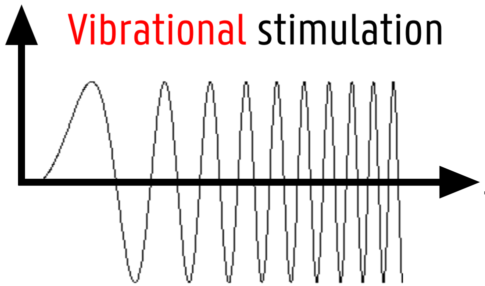
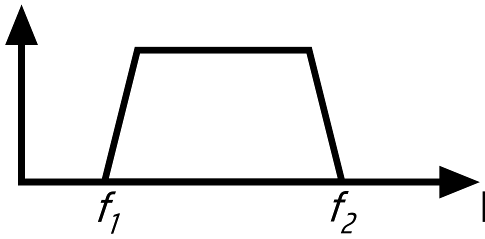
THERMOGRAPHY – VIBRO



Vibrothermography: Why not use a defect itself for heating ?!?

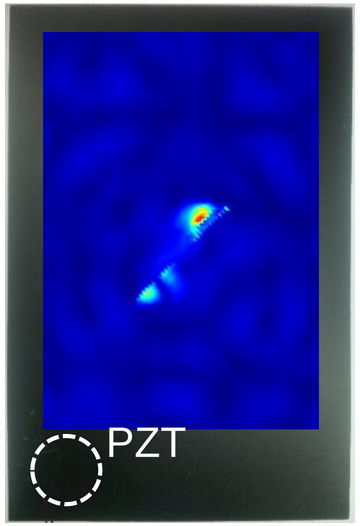




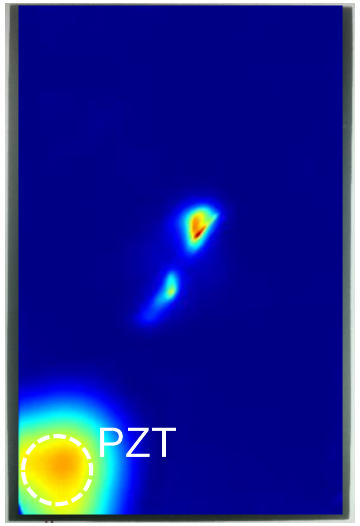
Has the potential to **outperform** all other excitation approaches !

Impacted [-45/0-45/90]$_{3S}$ CFRP

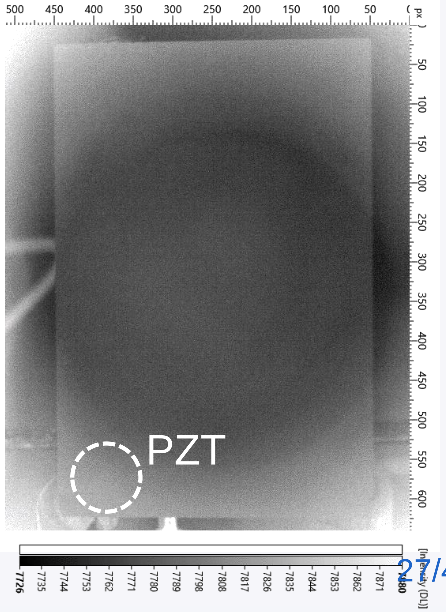
Vibrometry 129 kHz



Lock-in vibrothermography 129 kHz



Sweep vibrothermography 0-250 kHz



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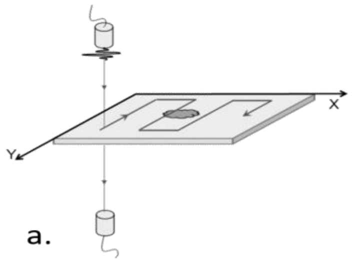
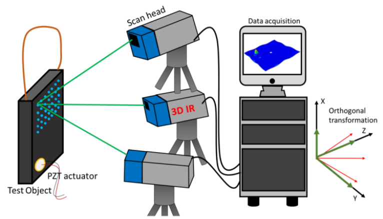
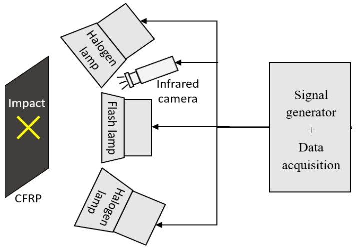
THERMOGRAPHY







	Ultrasound	Vibrometry	Thermography
Defect detection	+++	++	++
Defect sizing	+++	+	+
Depth estimation	+++	0	+
Material characterization	+++	++	-
Inspection time	-	++	+++
Contactless	0	+++	++
Complex geometry	-	++	++
Cost	-	-	++

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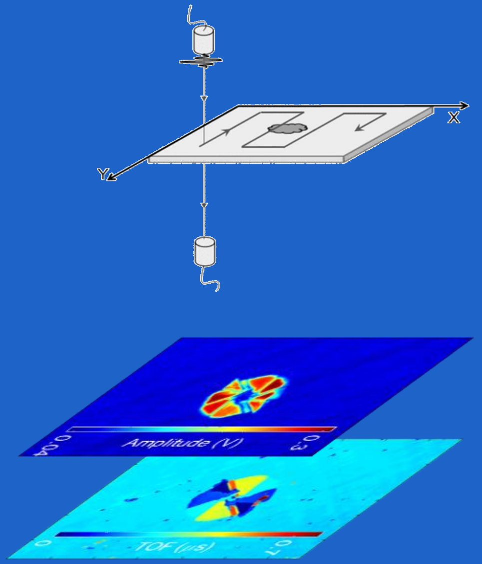
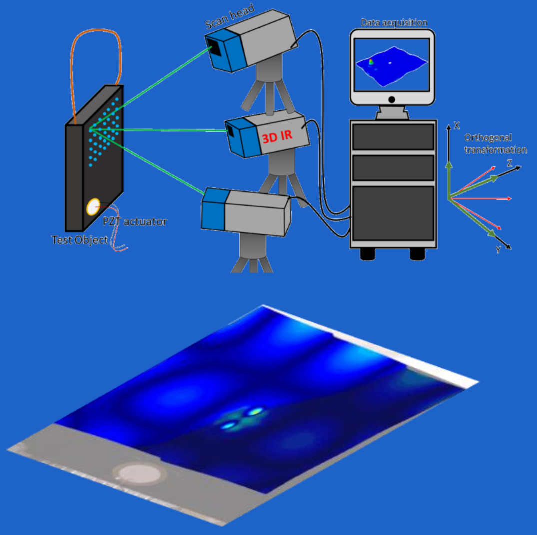
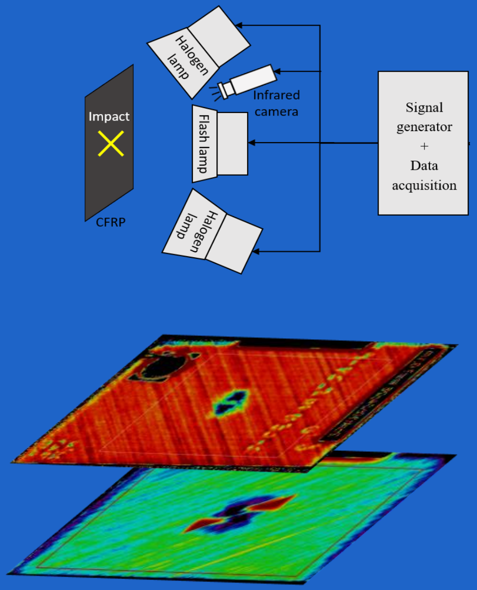




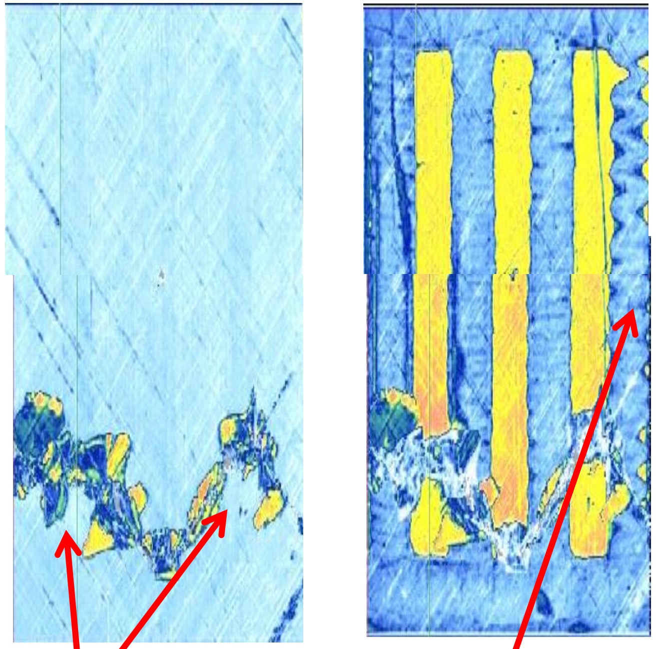


APPLICATION ON INDUSTRIAL PARTS

INDUSTRIAL SAMPLES

- Automotive sandwich CFRP failed under bending load

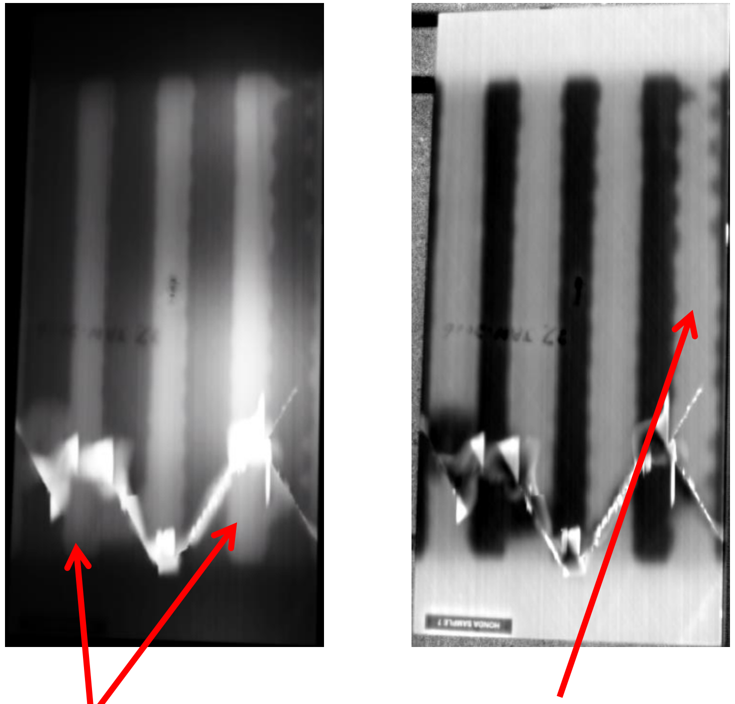
Ultrasound (1 hour)



Delamination

Wavy adhesive

Thermography (20 seconds)



Delamination

Wavy adhesive

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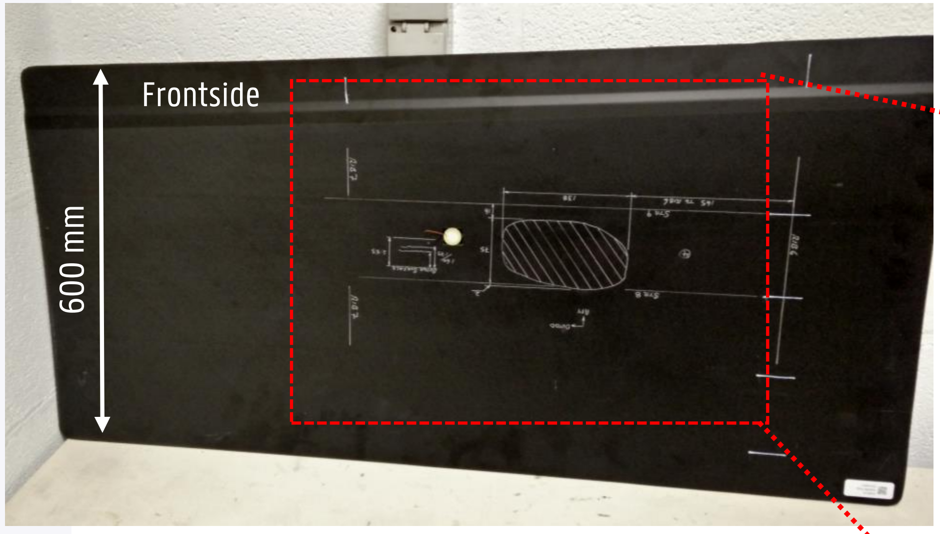
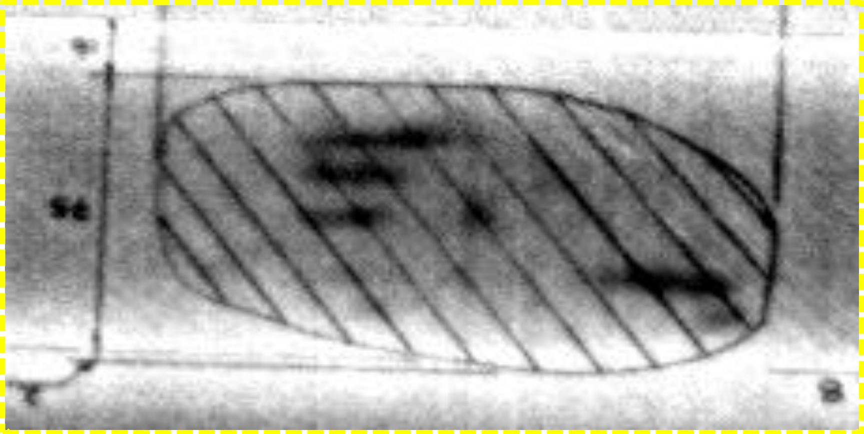
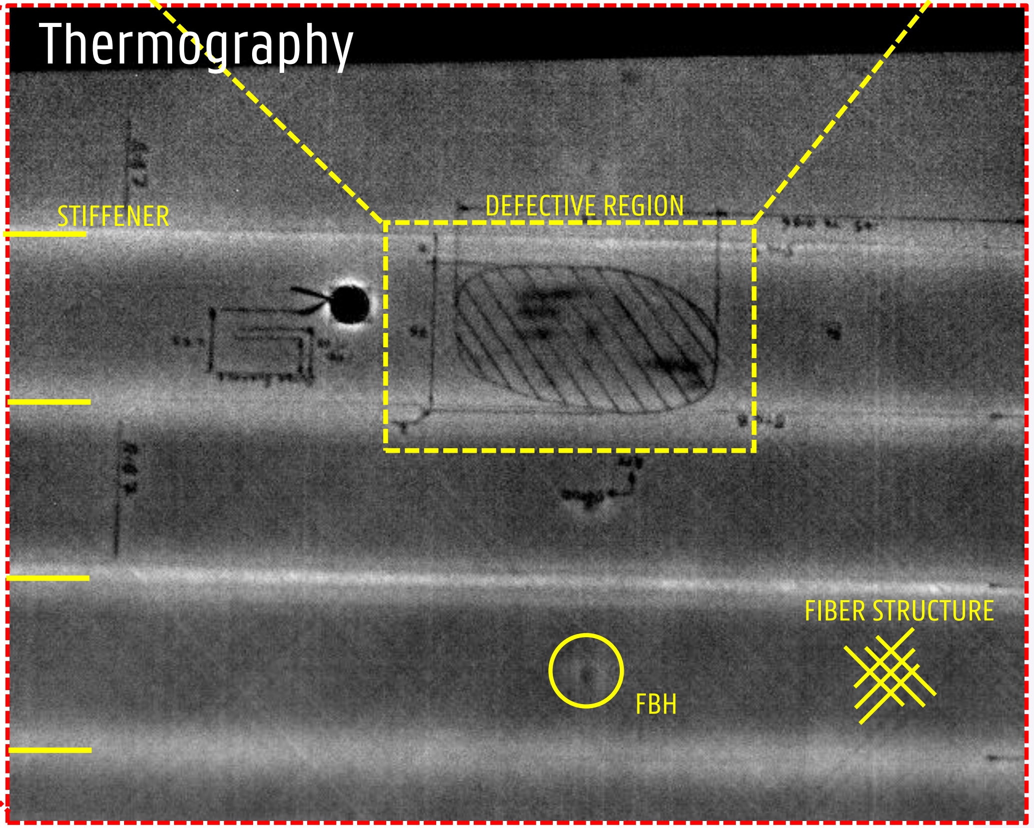
INDUSTRIAL SAMPLES

Airbus A400M stiffened flap panel

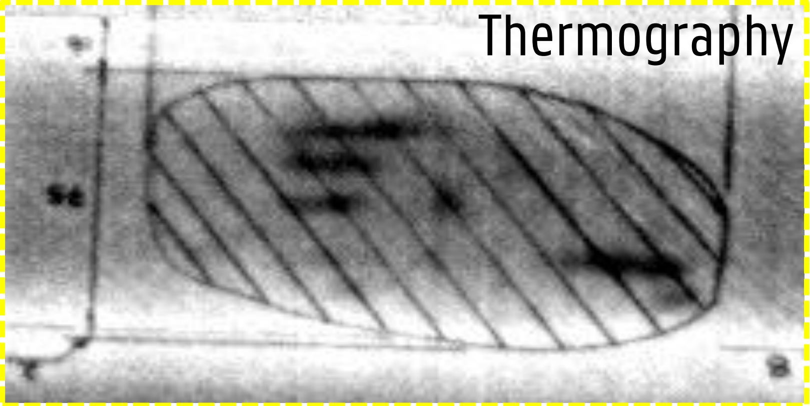


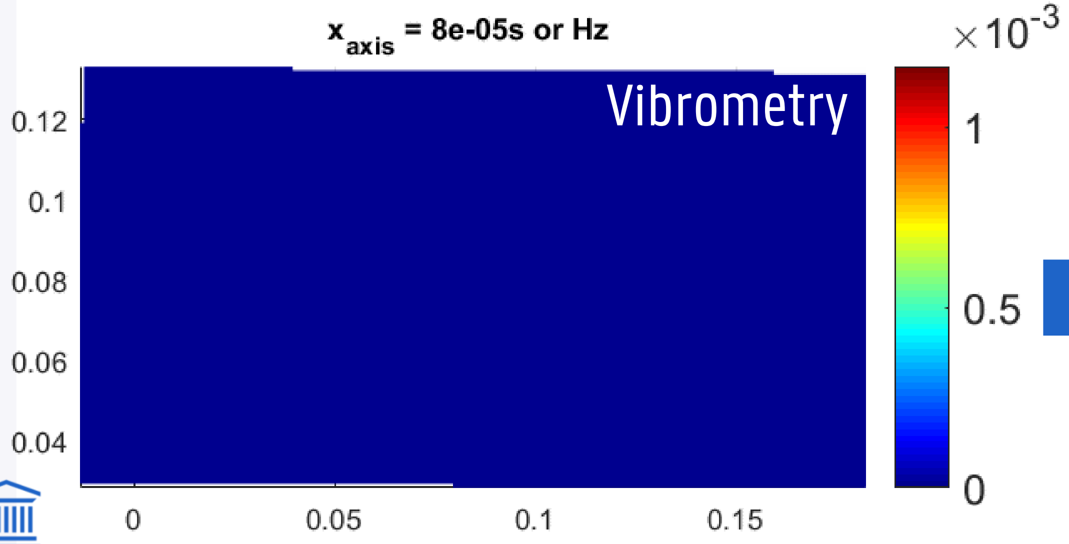




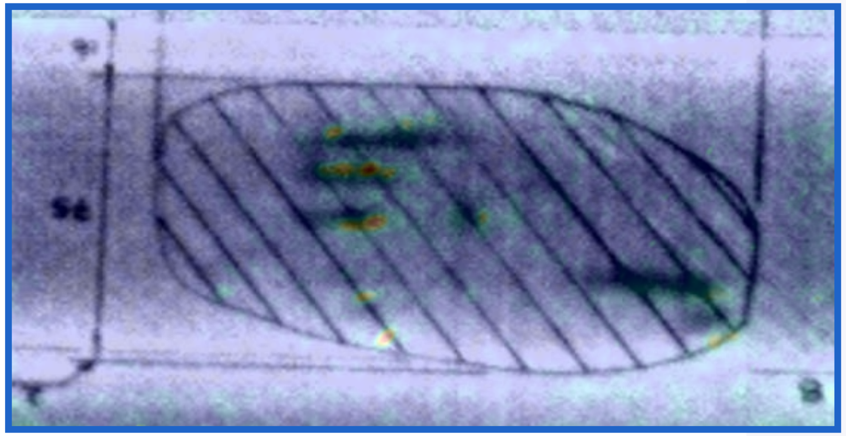
INDUSTRIAL SAMPLES

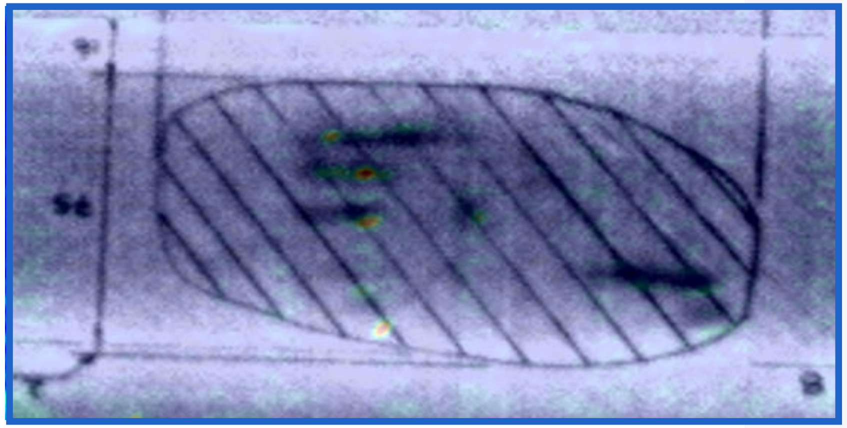
Airbus A400M stiffened flap panel





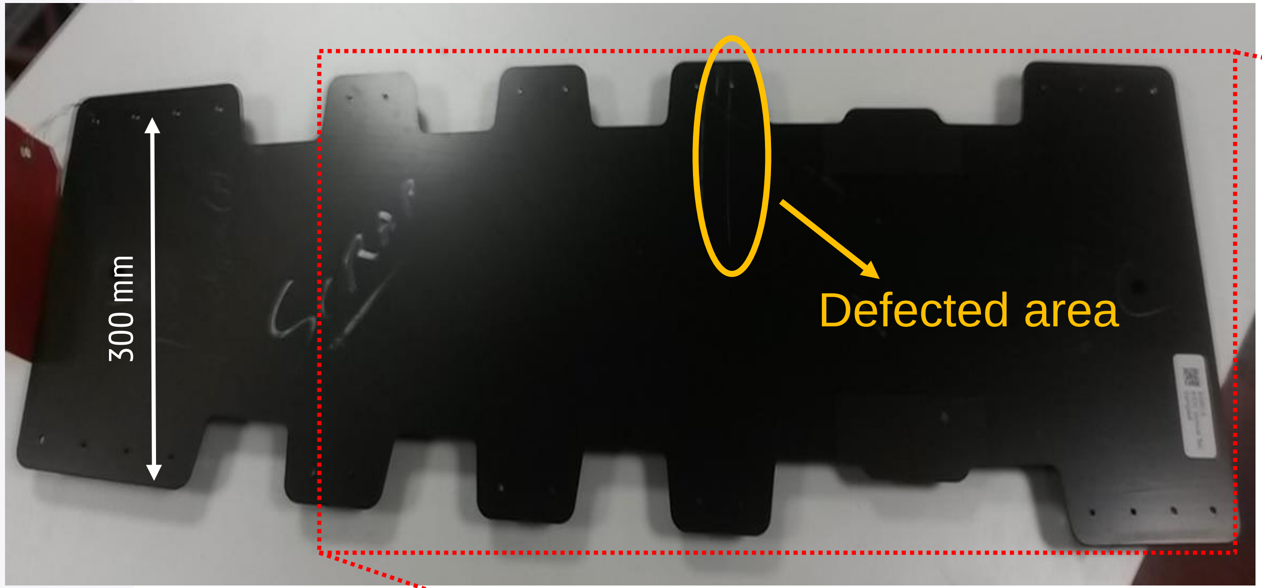
PROCESSING



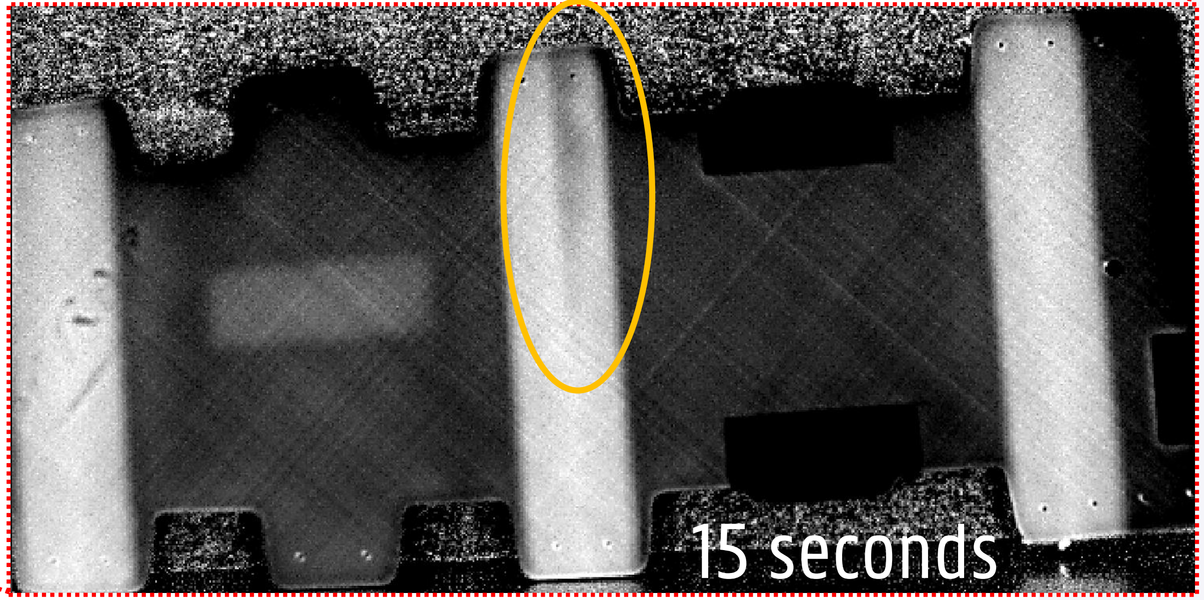


INDUSTRIAL SAMPLES

Airbus A320 stiffened vertical tail : defect at backside stiffener

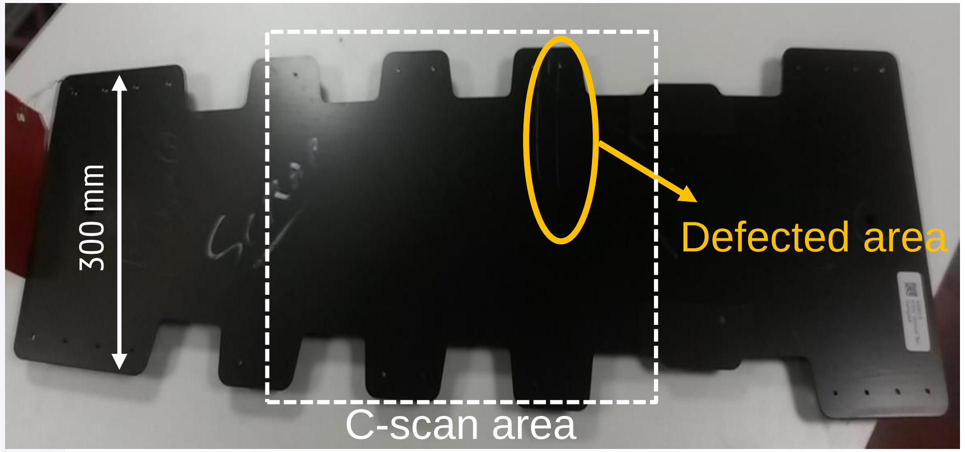


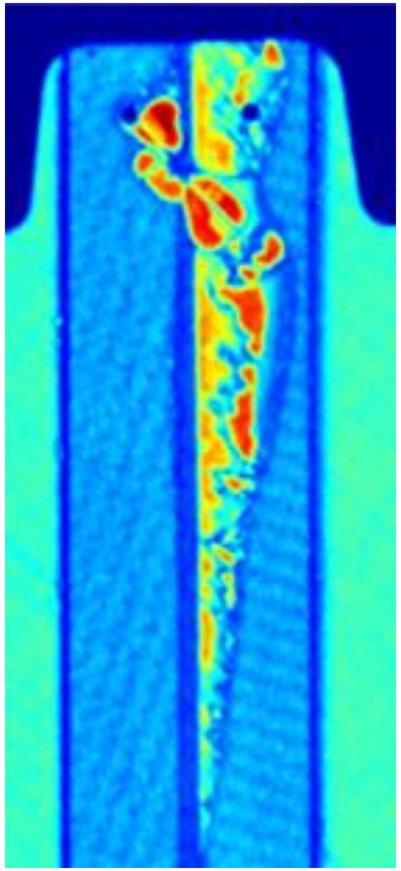
Thermography

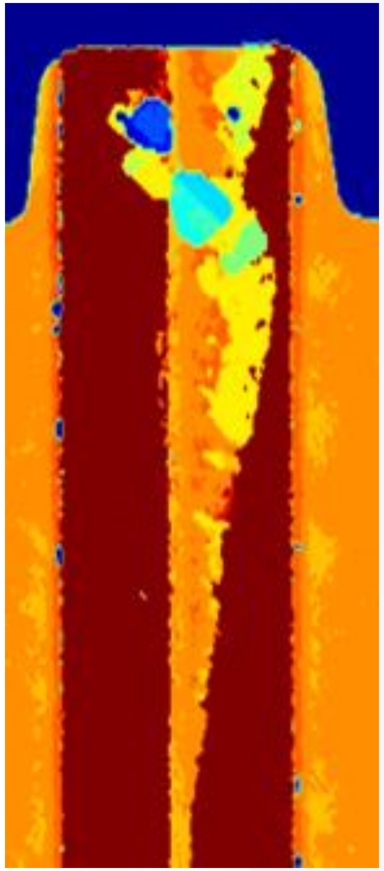


INDUSTRIAL SAMPLES

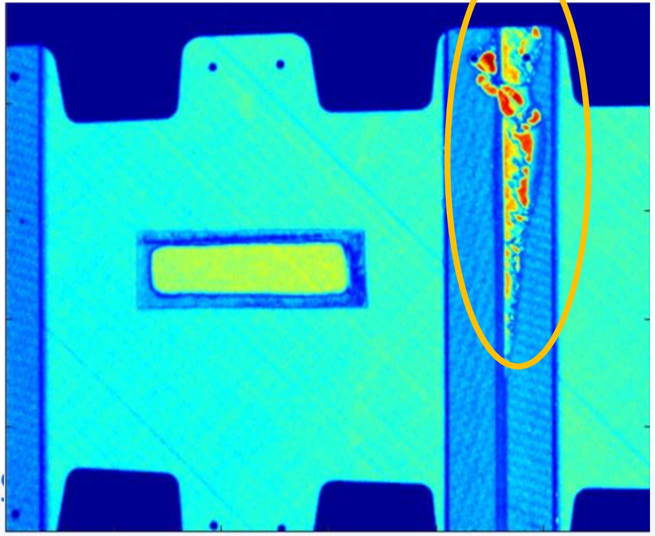
Airbus A320 stiffened vertical tail : poor bonding of stiffener + delamination at borehole

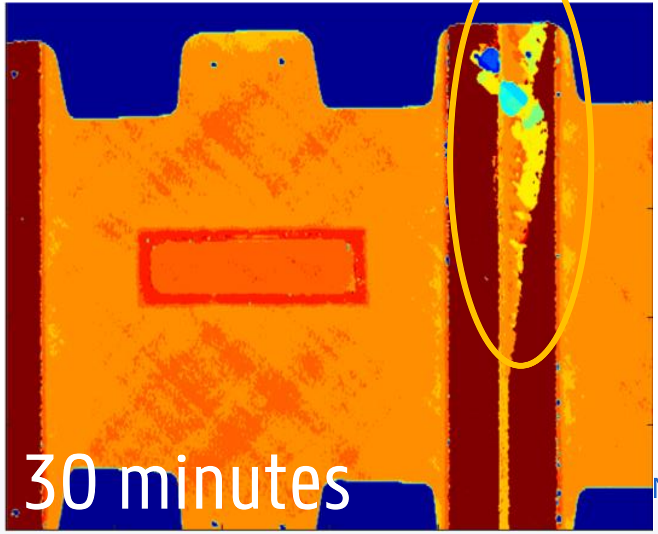






Ultrasound

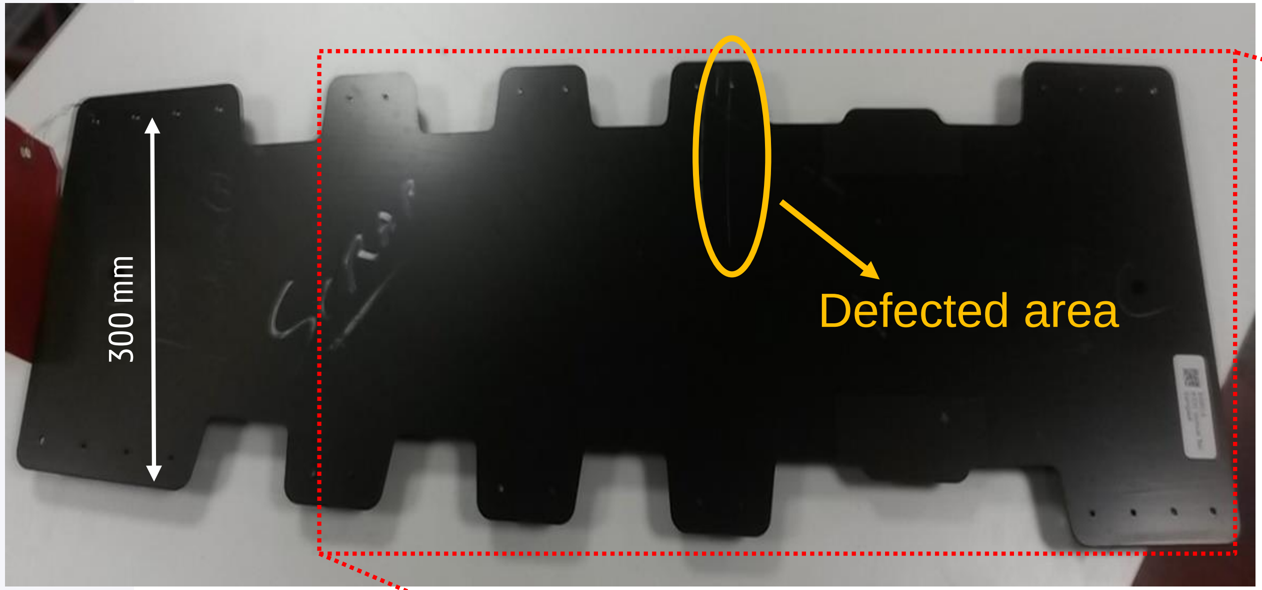




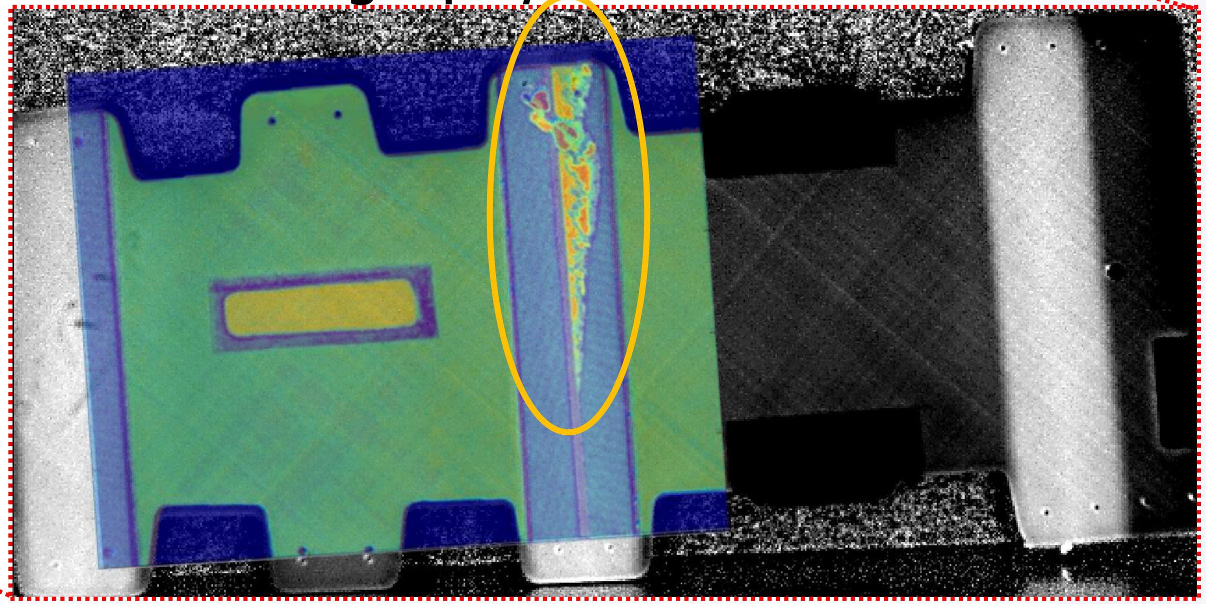
30 minutes

INDUSTRIAL SAMPLES

Airbus A320 Vertical tail : defect at backside stiffener

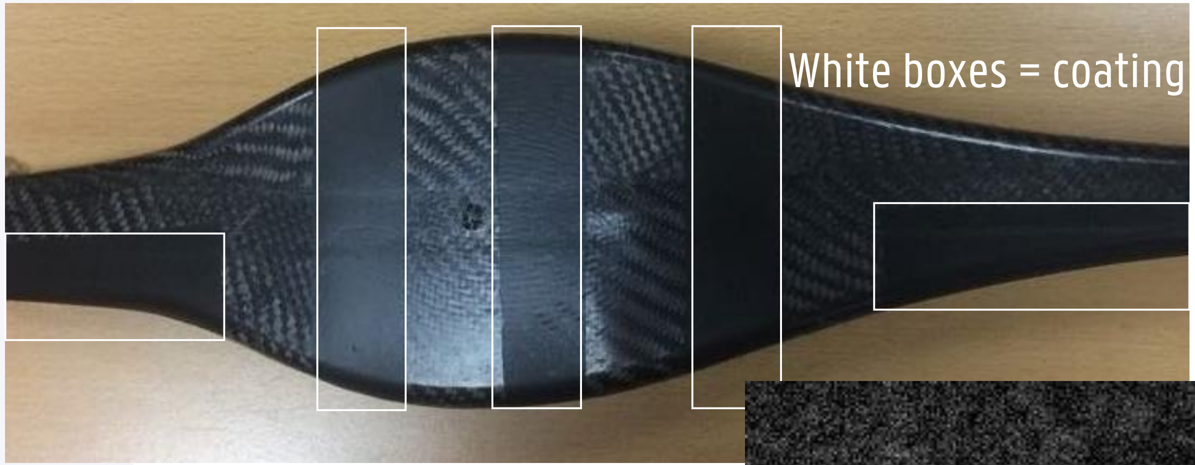


Thermography + Ultrasound

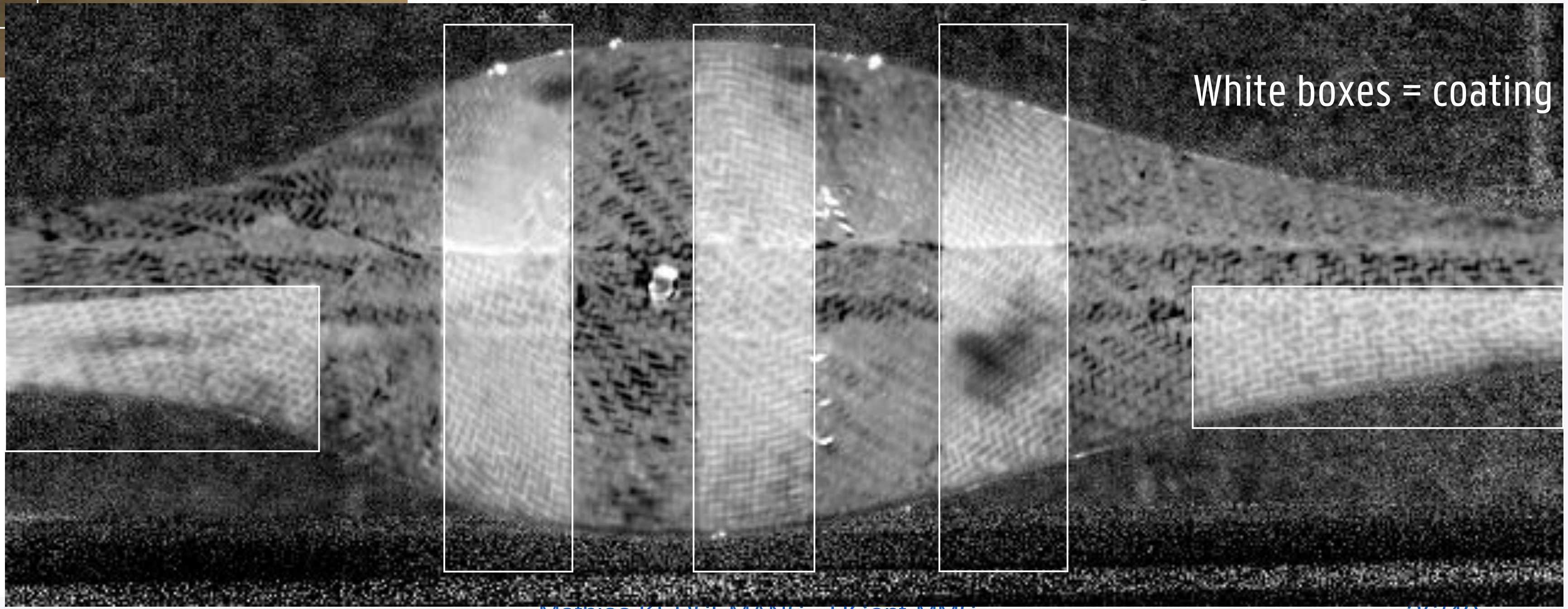


INDUSTRIAL SAMPLES

- Fiber architecture of painted CFRP fabric control arm



Thermography – 6 seconds



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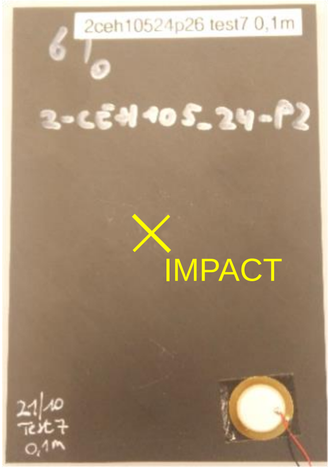
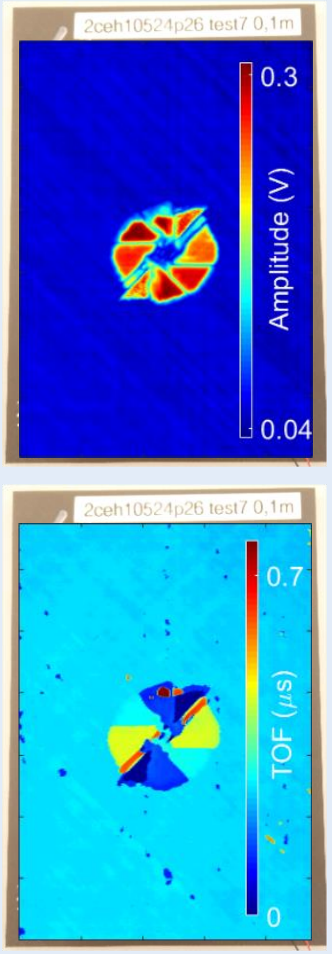
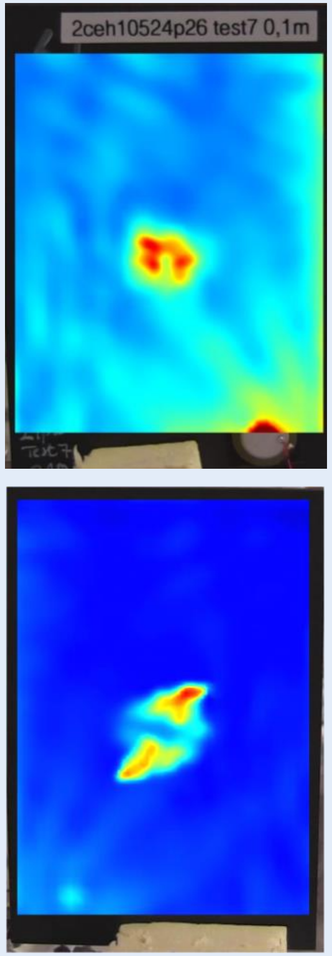
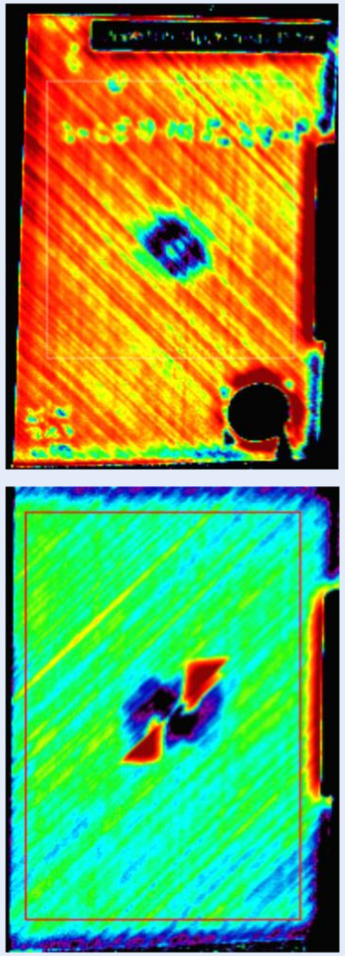
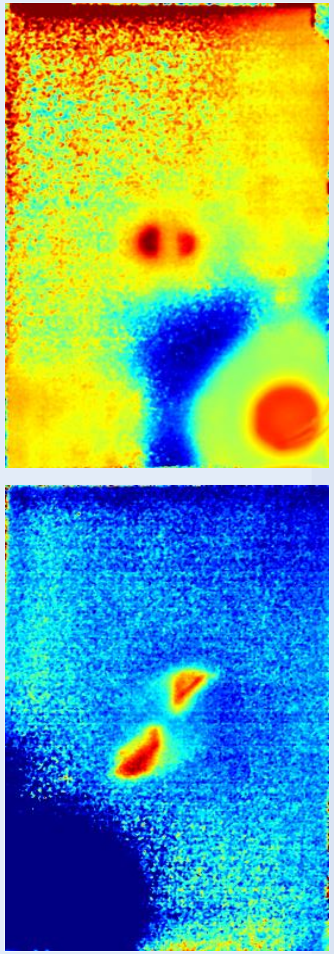
CFRP WITH BARELY VISIBLE IMPACT DAMAGE

Impacted
$[-45/0\text{-}45/90]_{3S}$ CFRP



Adaptive time-resolved ultrasound	Local Defect Resonance	Lock-in thermography	Vibro-thermography
			
20 min	2 min	30 sec	1 sec

CONCLUSIONS

CONCLUSION

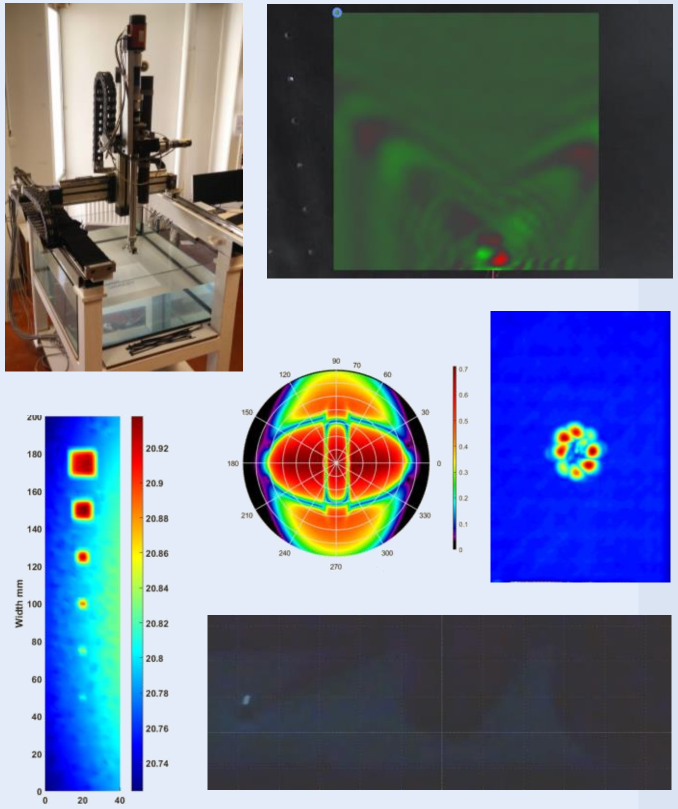
Fiber reinforced polymers

- **Complex** mechanical behavior
- Susceptible to **internal damage** features

UGent-MMS can deal with this through …

- ✓ Wide competence on fiber reinforced polymers
- ✓ Experimental-numerical approach
- ✓ Unique and advanced research facilities
- ✓ Strong links with both academia and industry

NDT



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Work in our lab ?

- 3 open PhD vacancies
- 1 open PostDoc vacancy

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This research has received funding from different sources

- Fonds voor Wetenschappelijk Onderzoek Vlaanderen FWO
- Bijzonder OnderzoeksFonds UGent BOF
- Strategic Initiative Materials SIM – M3 program

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