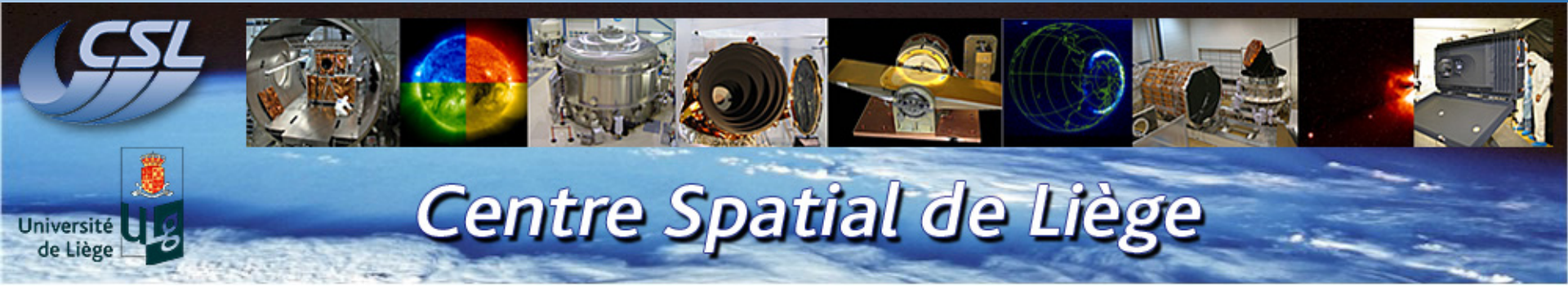

Non-contact emerging nondestructive techniques for aerospace composite inspection

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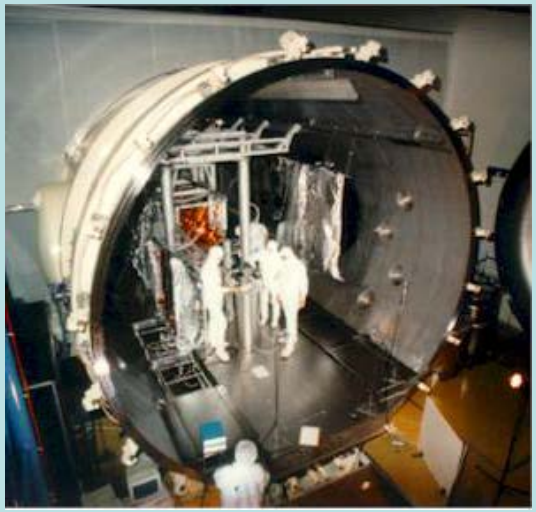
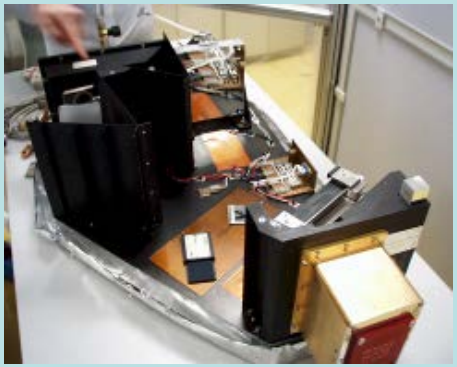
Centre Spatial de Liège

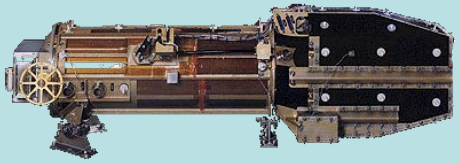
« Center of Excellence » in Optics for the European Space Agency

Simulated space environment testing
Large chambers with optical benches



Development of optical
Space instrumentation





Development of
Advanced Technologies

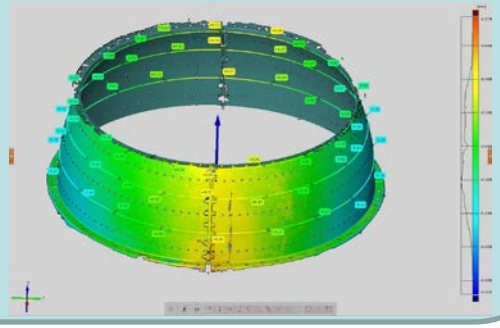
- Vacuum-Cryogeny
- Quality insurance
- Thermal Design
- Signal Processing
- Spaceborne Electronics
- Smart sensors
- Surface processing
- Optical Design
- Optical Metrology
- Non Destructive Testing

The Laser & NDT Lab

Research in laser and optical metrology and NDT for aerospace

Dimensional measurement

- Fringe projection
- Digital Image Correlation

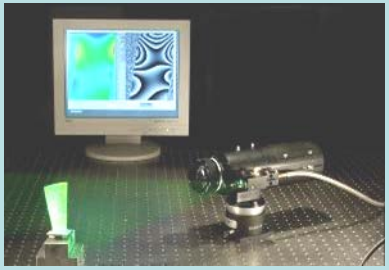


Thermography

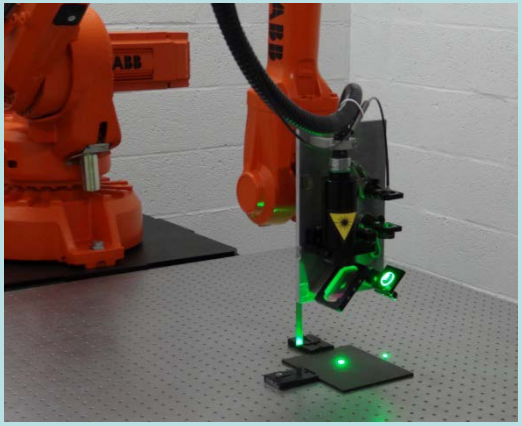
- Pulsed + Lock-in
- Vibrothermography (ULg)

Deformation measurement

- Holography
- Speckle interferometry
- Shearography



Laser Ultrasonics



NDT of composites

- Applications
  - Non destructive inspection of composites (foreign materials, damages,…)
  - Non destructive testing of composite structures (CTE measurement,….)
- Main role of CSL in recent/current projects:
  - Compare non-contact NDI techniques based on **optics/lasers**
  - Develop new techniques/sensors
  - Projects led by industries
  - Projects funded by EU, Wallonia

e.g. TECCOMA (2015-2019)

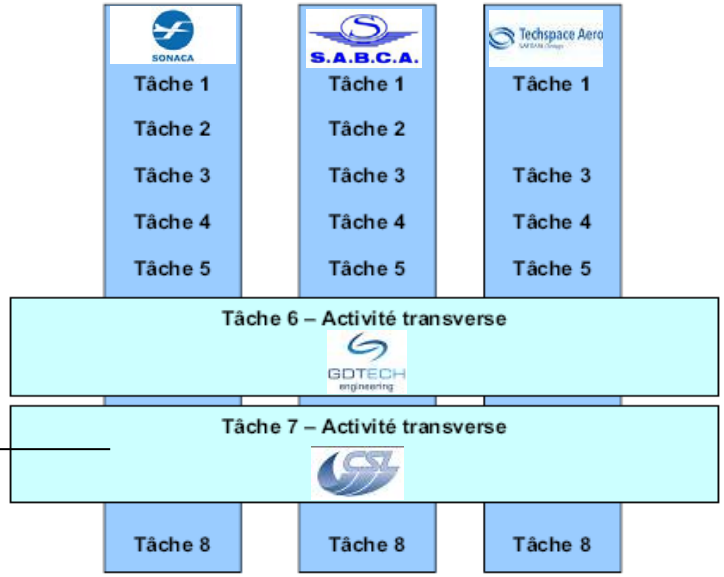
Wallonie

Holography/Shearography

IR Active Thermography

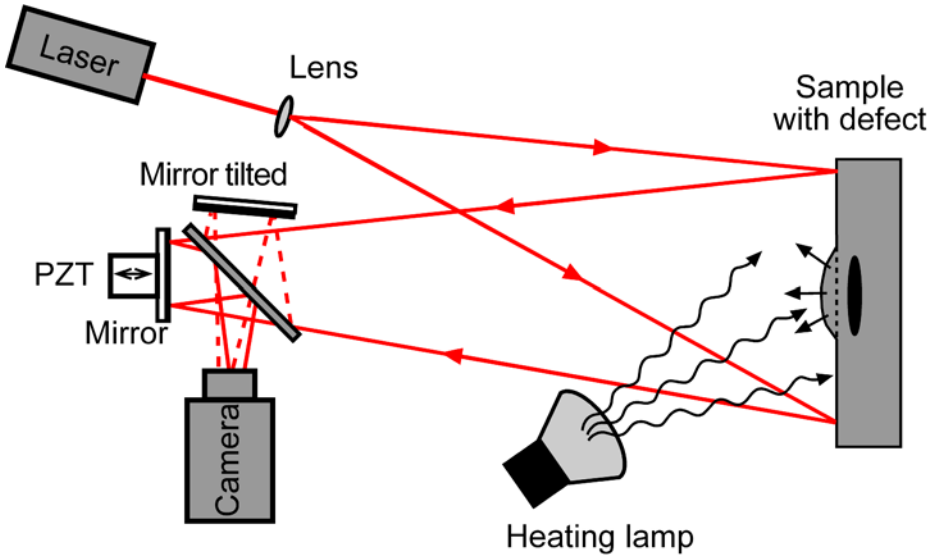
Laser Ultrasonics

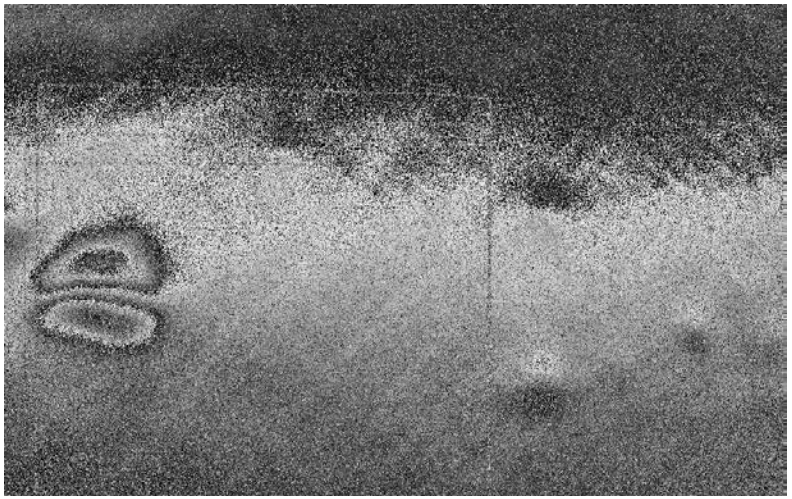
NDT/NDI

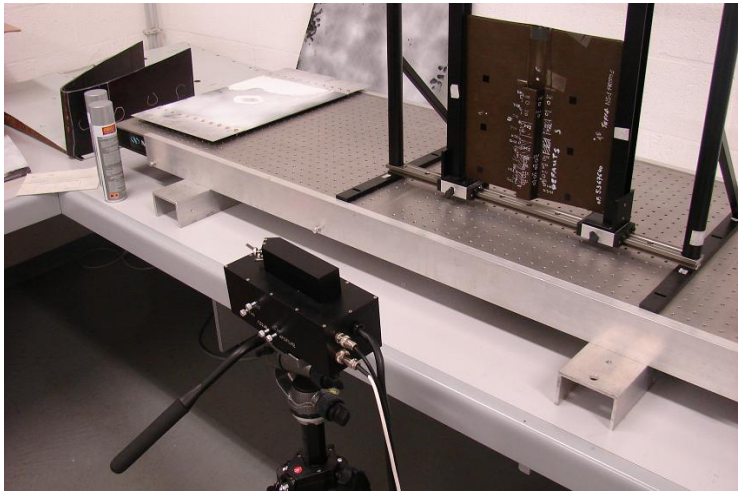


Shearography

- Shearography with heating

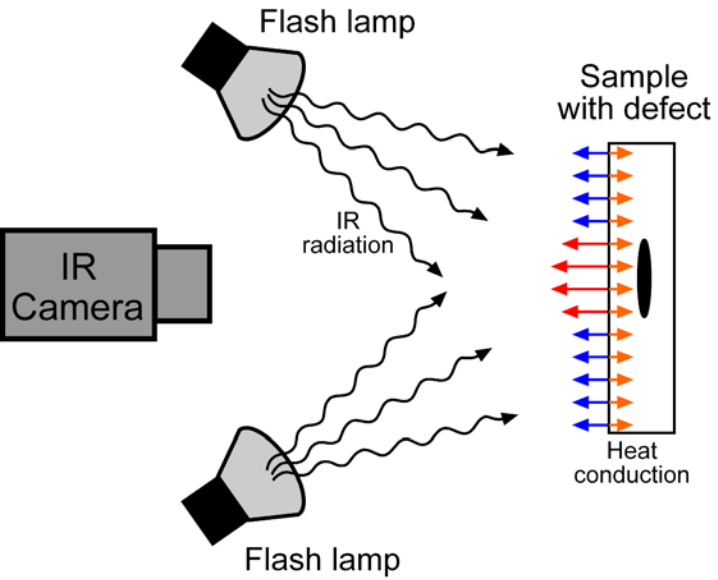




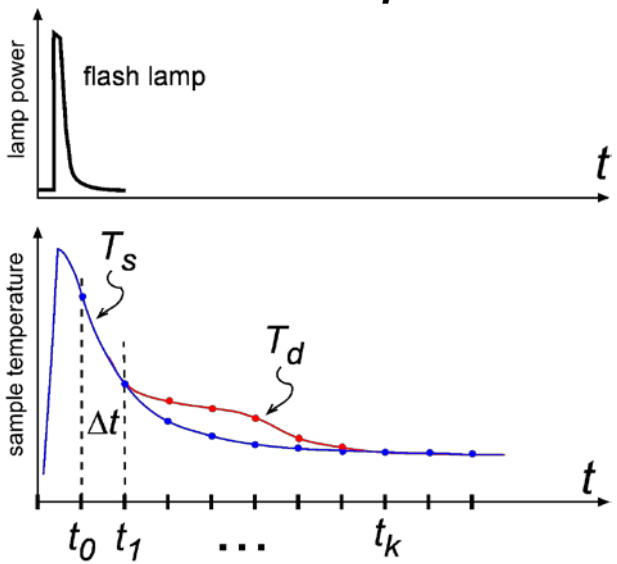


Infrared Thermography

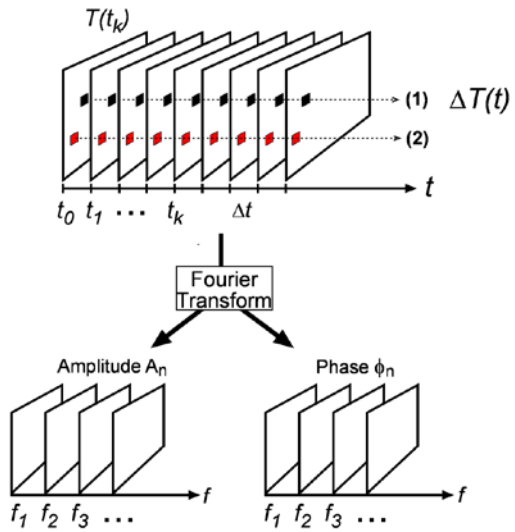
- Various techniques



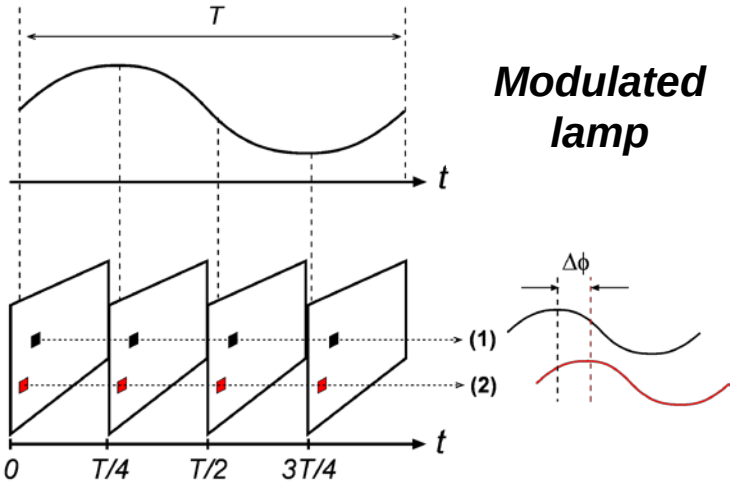
Flash lamp

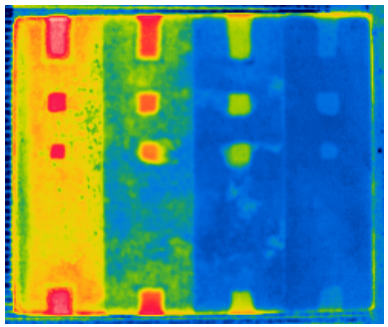


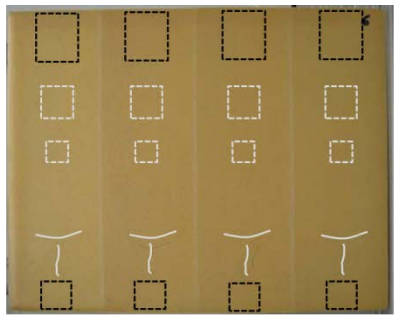
Fourier processing



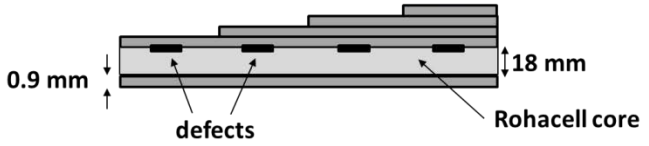
Modulated lamp







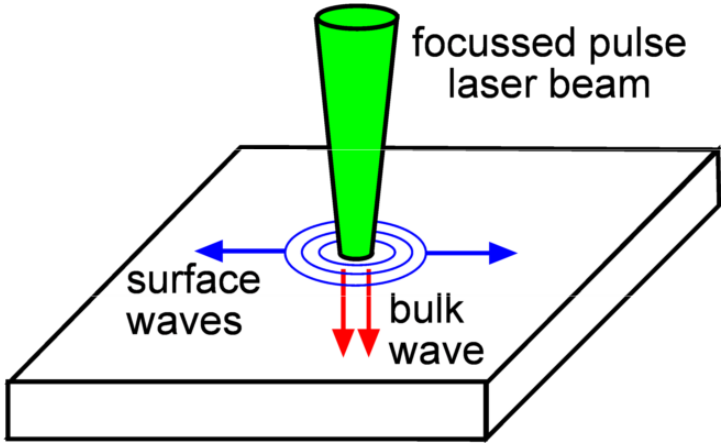
Debonding 30x50 mm²
Cracked core 20x20 mm
Cracked core 15x15mm
Cracks
Debonding 30x30 mm²



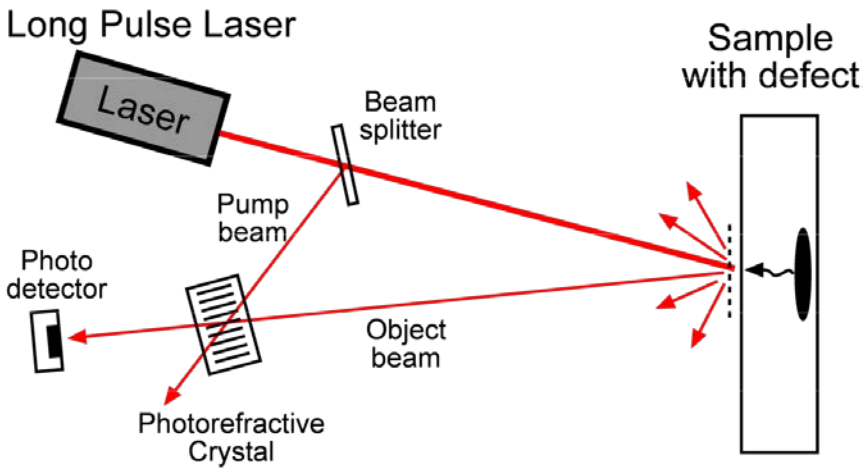
Laser Ultrasonics

- **Principle**

Generation of ultrasound by laser
Thermoelastic effect



Detection of ultrasound by laser
Interferometric probe (with laser) and Two-Wave Mixing



- ✓***No couplant – No water***
- ✓***Signal independent of geometry***
- ✓***Economically interesting for curved parts (see. Airbus-Lockheed Martin publications)***

Laser Ultrasonics

- **First tests with LUIS - Laser ultrasound system of CTA (Montreal)**
- **Detection Two-Wave Mixing (TWM) + long pulse laser (PDL)**
- **Generation by CO_2 laser (10.6 µm)**

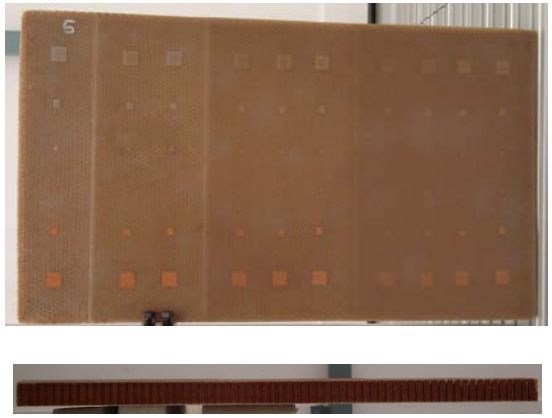
  Laser illumination brought by a complex articulated arm with mirror (flexibility problems)

- **Generation : pulsed CO_2 laser (10.6 µm)**
- **Detection : pulsed YAG laser (1064 nm)**
- **Probe TWM**
- **repetition rate : 100 Hz**
- **Laser Spot : 2 mm**
- **Scanning step : 0,5 mm**
- **manufacturer TECNAR**

Samples

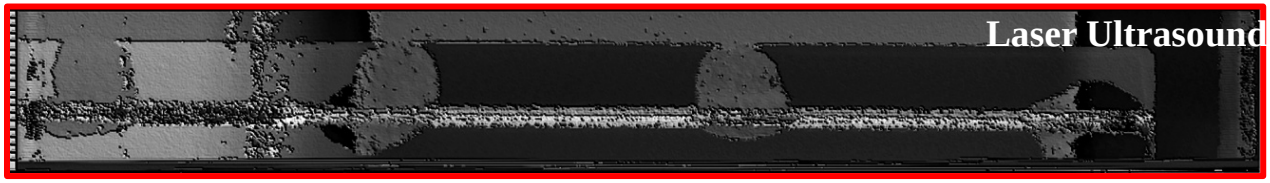
- Compared studies on various structures with defects

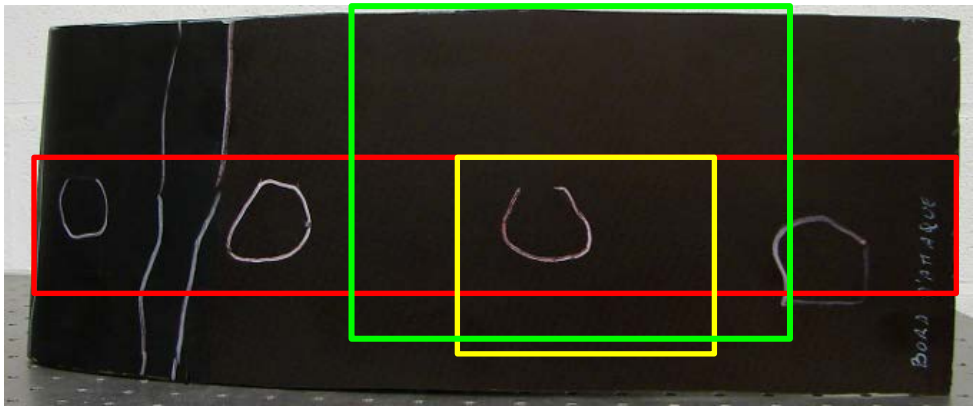
Monolithic CFRPs



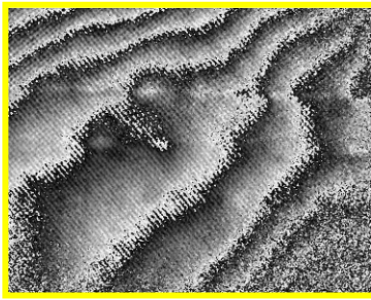
Sandwich CFRP/GFRP

Compared results

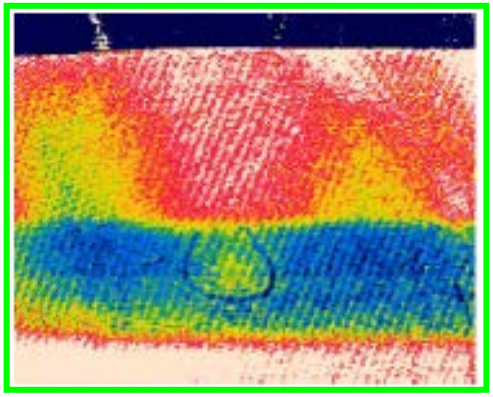


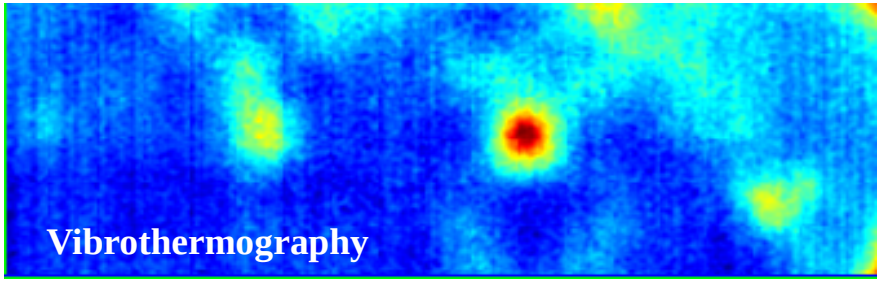


Shearo

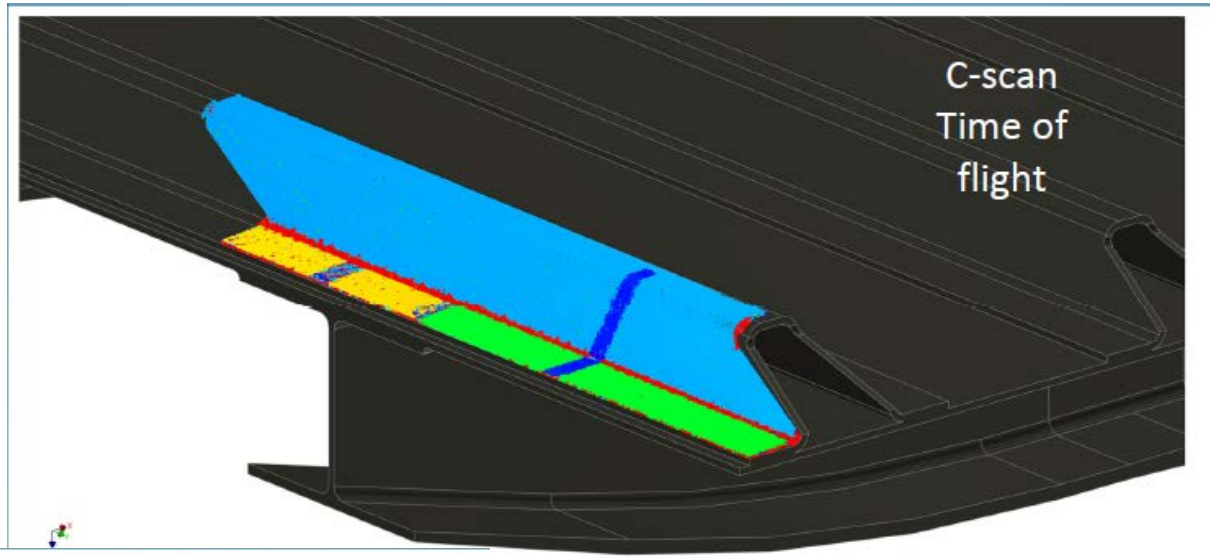


Optical pulse thermography





Laser Ultrasound Results



Comparison

	Thermography	Shearography	Laser UT
Depth	1,5 mm	> 1,5 mm	>>> 1,5 mm
Dimensions	3-4 mm	3-4 mm	2 mm
Interpretation	+	-	++
Measurement	Qualitative	Qualitative	Quantitative
Depth assessment	-	-	++
Set-up	+	+	- (scanning)
Cost	$$	$	$$$$

Calibrated Defects are made of teflon to represent delaminations for UT technique
No fast conclusion !

NDT techniques must be envisaged in complementarity

Our recent/current developments

- Combination of holography/IR thermography

  IR holography

- Robotized fully fiber-coupled laser ultrasound system

- Improvement of holography-shearography

  Post-processing techniques

- Data Fusion between various NDT techniques
- Combined experimental-simulated NDT
- Terahertz Holography NDT

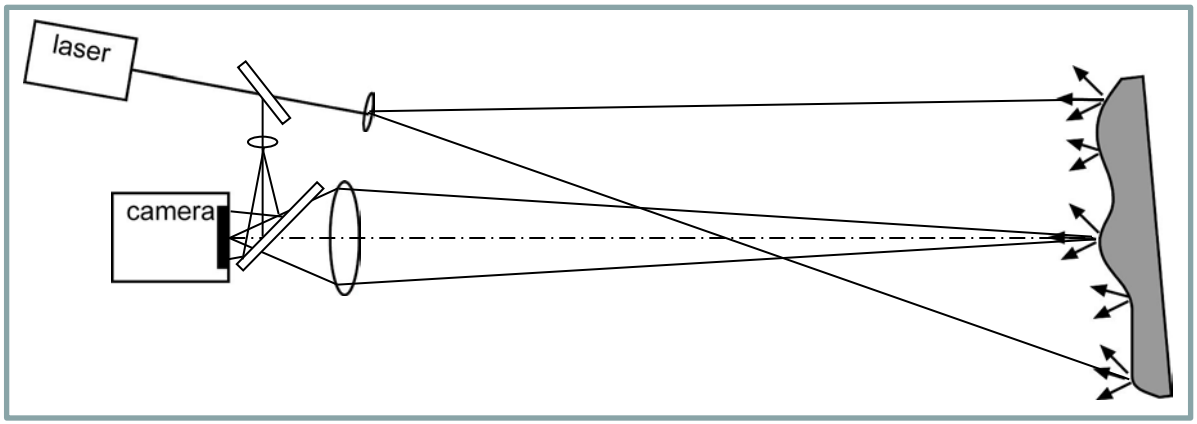
IR Holography: motivation

- **IR Thermography and Holography/Shearography**
  - Imaging full-field, non-contact (except for some excitation)
  - Require excitation
- **IR Thermography**
  - Easier interpretation of images than holo/shearography
  - A lot of post-processing methods exist
    - Allow defect depth assessment
  - Better introduced than holo/shearography in many fields
- **Why using holographic techniques in NDT ?**
- **Holography provides mechanical information**
  - Behavior of structure and damage during life-cycle
  - Propagation of damage depending on thermo-mechanical load
- **In many experiments :**
  - Temperature variations **AND** deformations need to be captured
  - Both in space and time

Combine holography and thermography

IR Holography

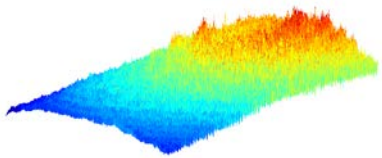
- Principle



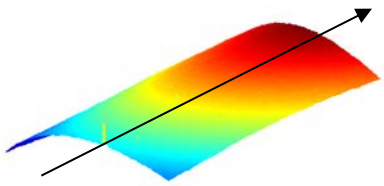
Single sensor
Simultaneous measurement of
- **Temperature variation**
- **Deformation**

FANTOM

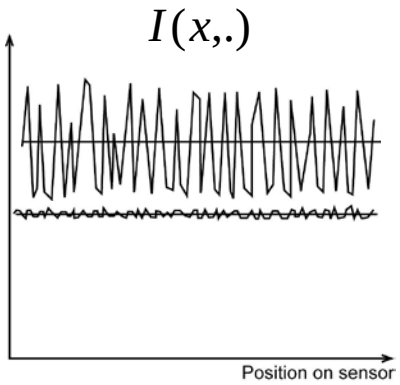
$$I(x,y) = I_{\text{thermal}}(x,y) + I_{\text{average}}(x,y) + C(x,y)\cos[\psi(x,y)]$$



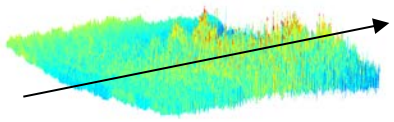
Laser **OFF**



Thermal background



Laser **ON**

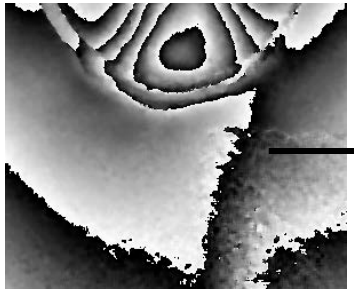


Hologram

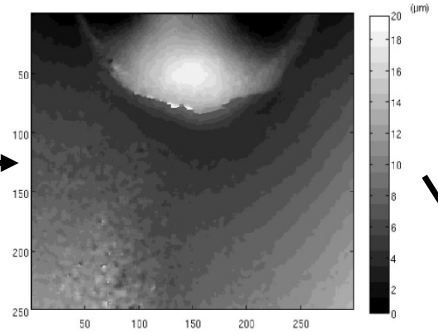
IR Holography

- Decoupling temperature and deformation

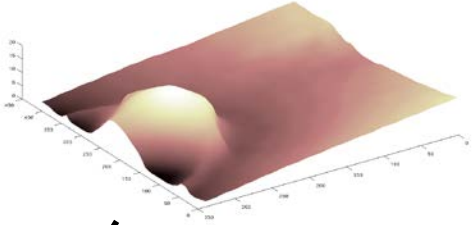
Wrapped phase

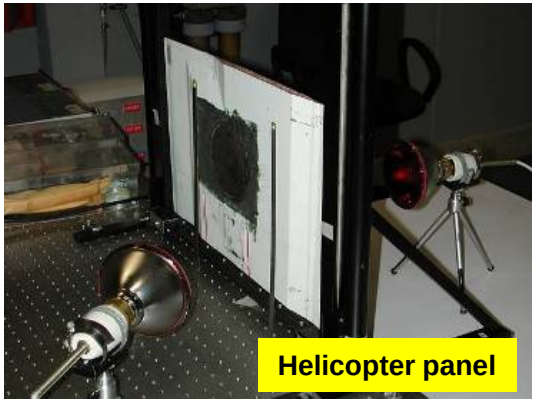


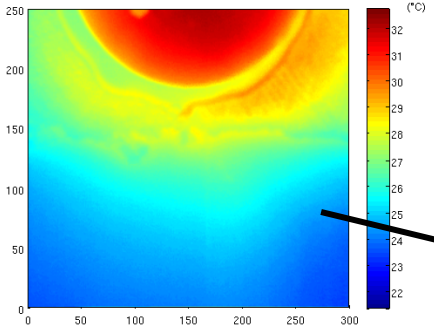
Unwrapped phase



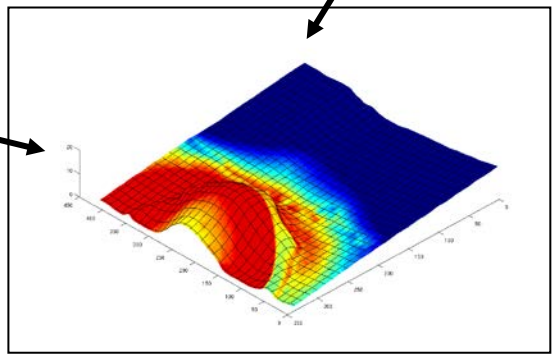
3D plot of deformation







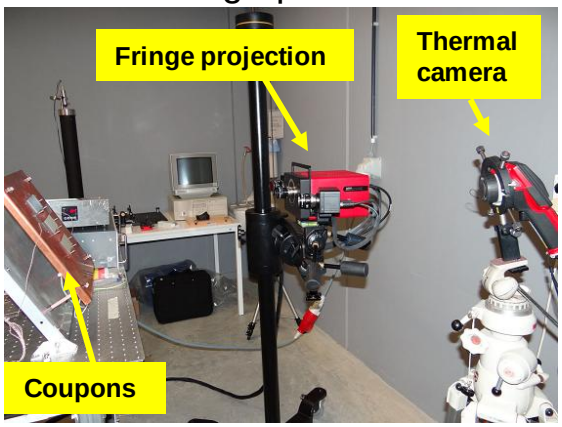
Temperature variation



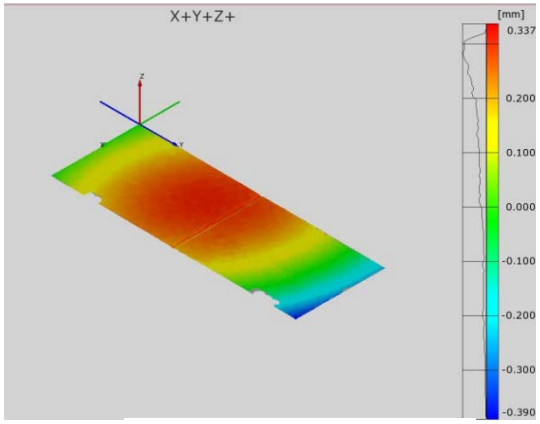
IR Holography

- Thermo-mechanical assessment of composite coupons

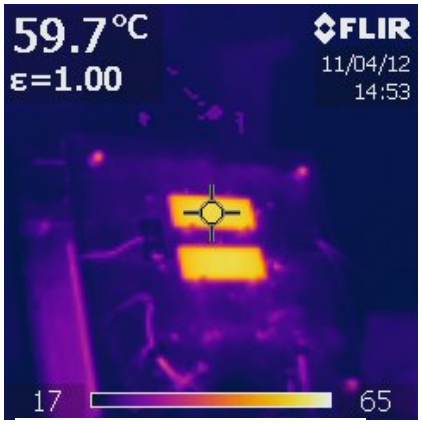
(a) Fringe projection + Thermographic camera

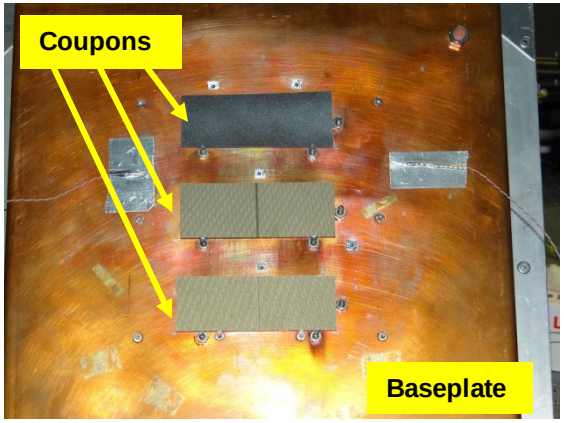


(b) Fringe projection deformation

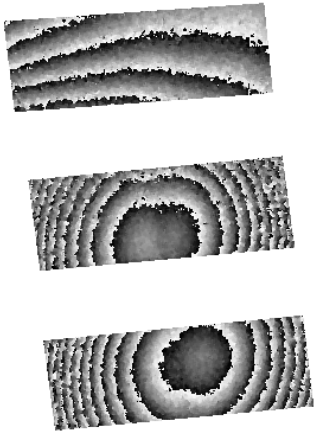


(c) Thermogram

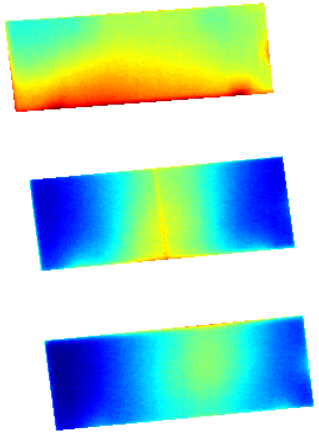




(d) Coupons on heating baseplate



(e) FANTOM deformation



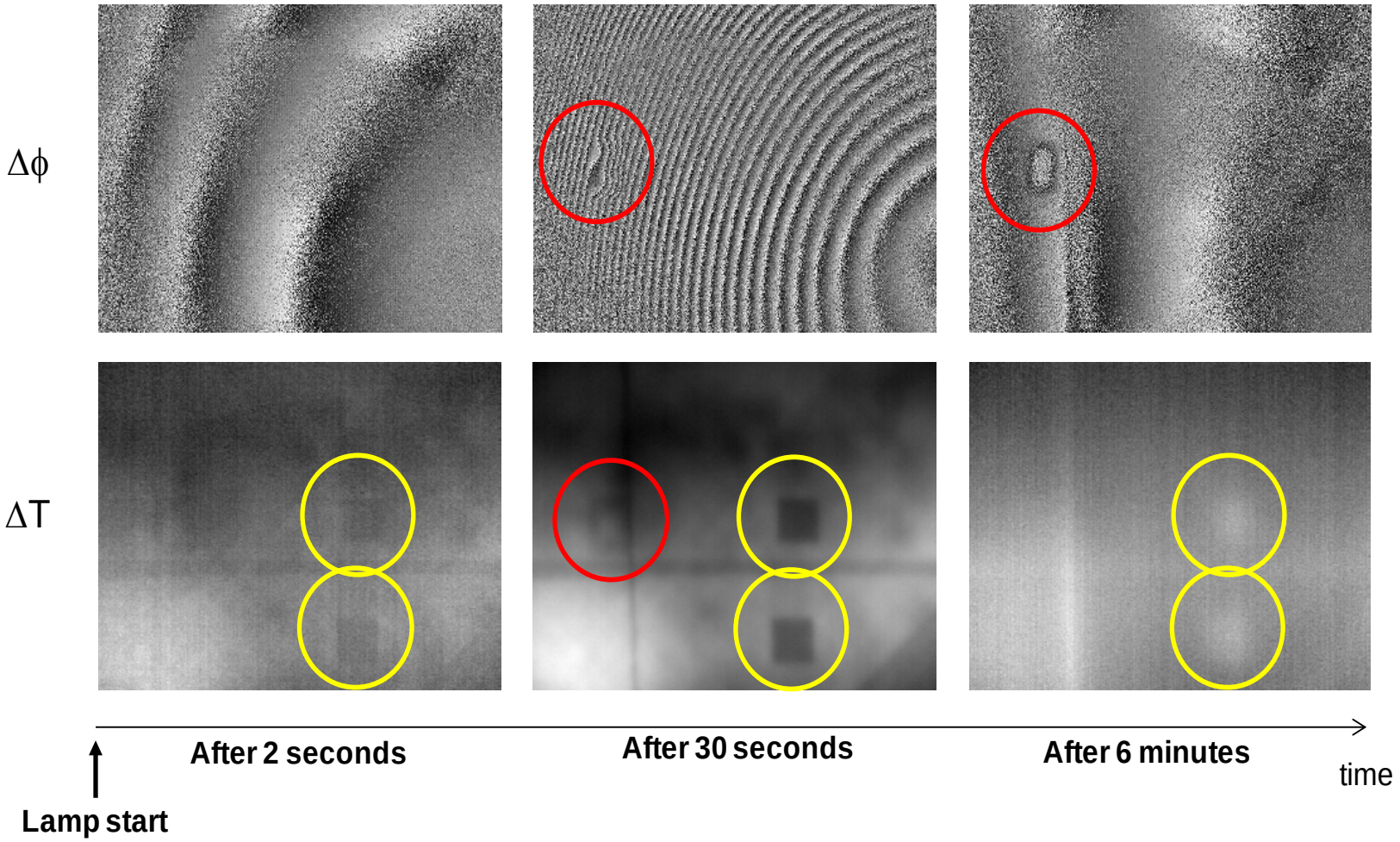
(f) FANTOM thermogram

IR Holography

- Airbus on-site testing

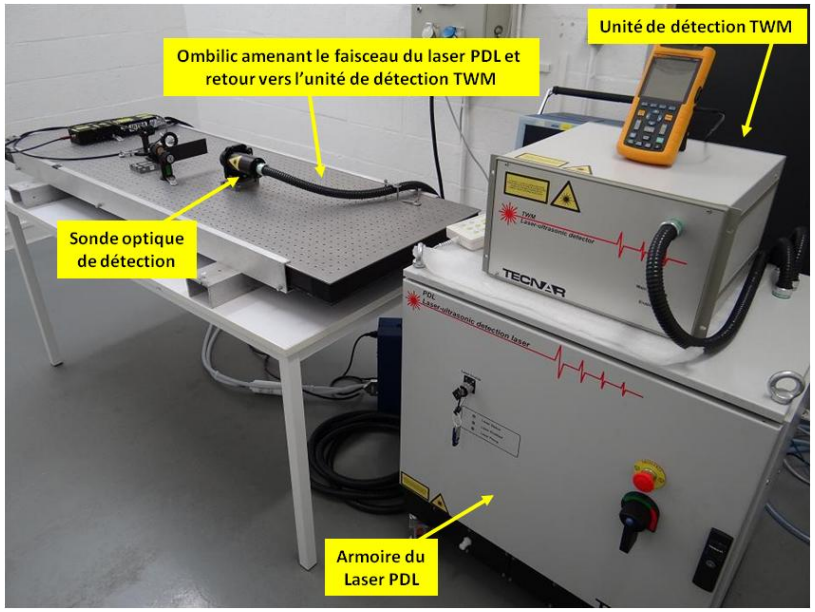
IR Holography

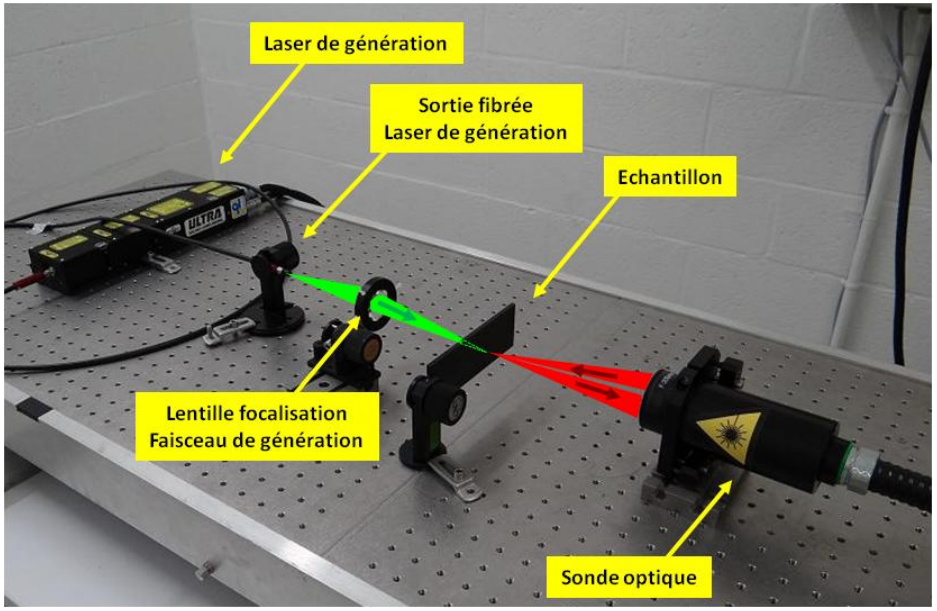
- Industrial tests : delamination on composite



Development of Laser Ultrasonics

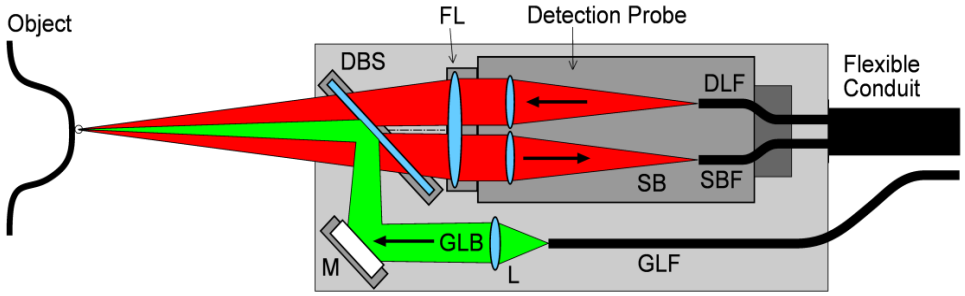
- Detection by Two-Wave Mixing
  - fiber-coupled system by Tecnar
- Generation by YAG laser (green)
  - fiber-coupling by CSL
- Robot arm (6 axes)

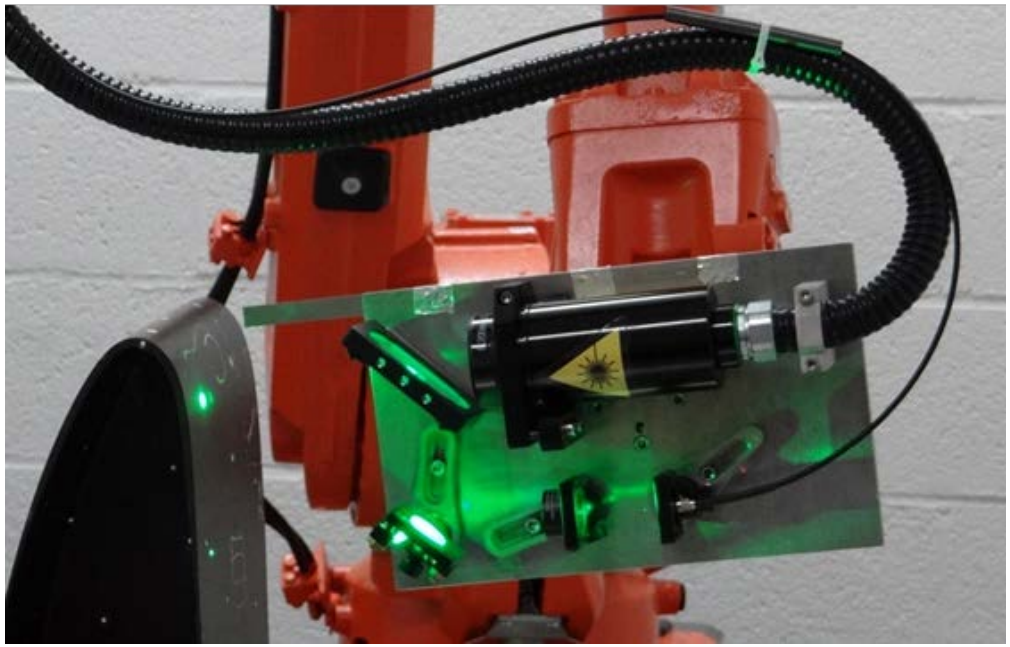


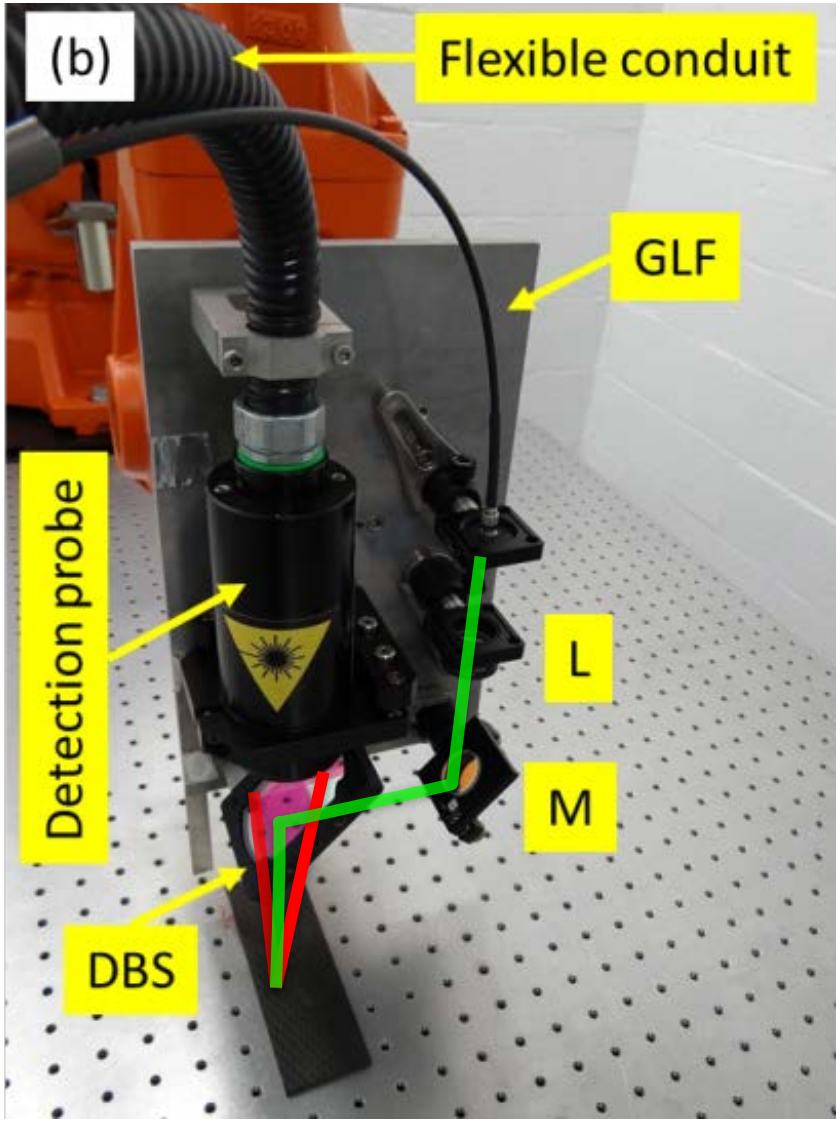


Development of Laser Ultrasonics

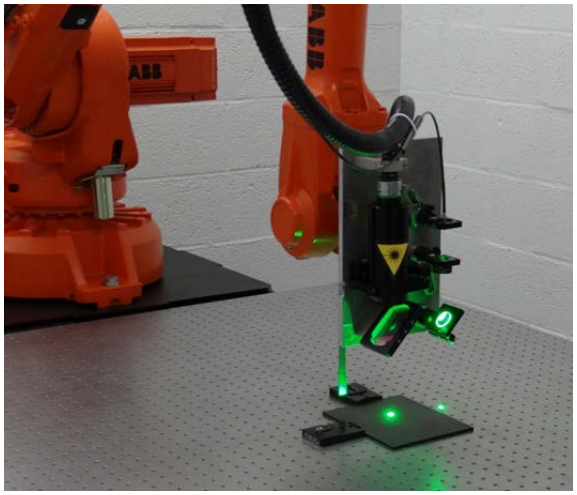
- Development of optical head



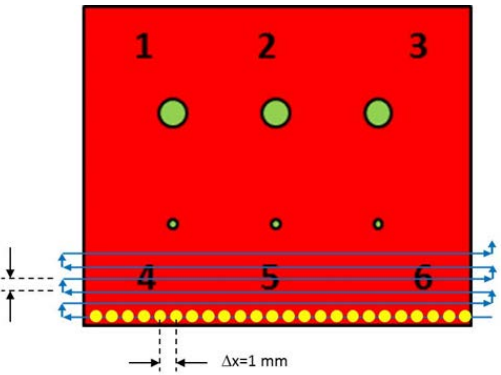




Development of Laser Ultrasonics



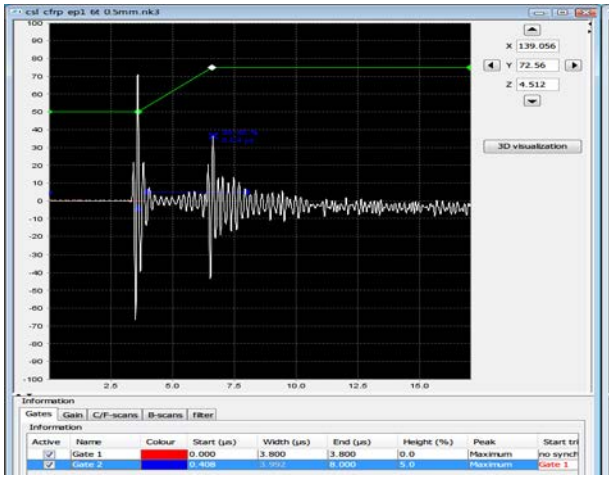
CFRP sample
Flat bottom holes
2 sizes – 3 depths

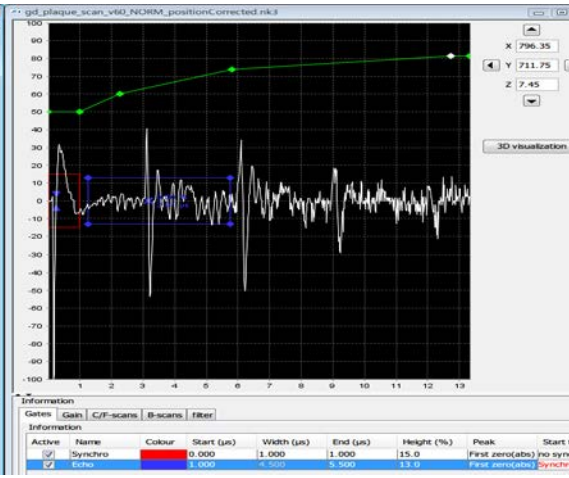


CSL system (532 nm)

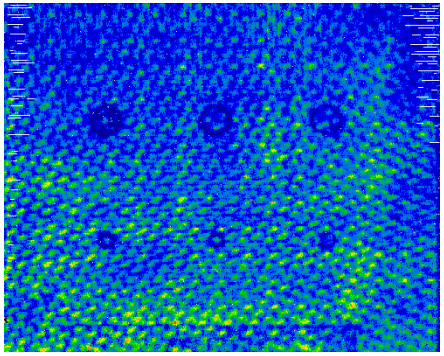
LUIS (10 µm)

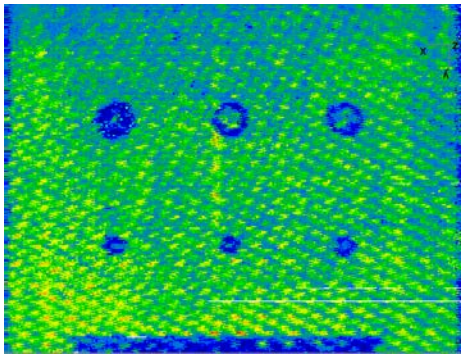
A-scan



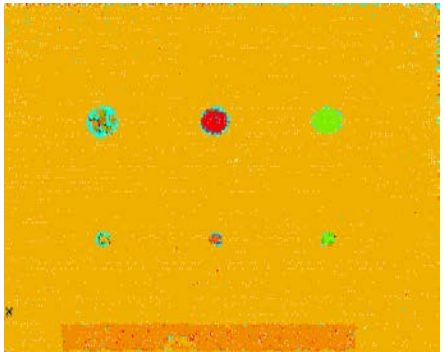


C-scan Amplitude

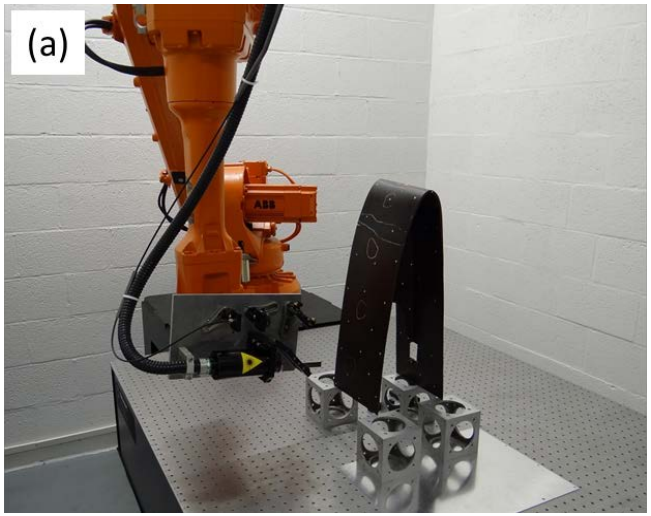




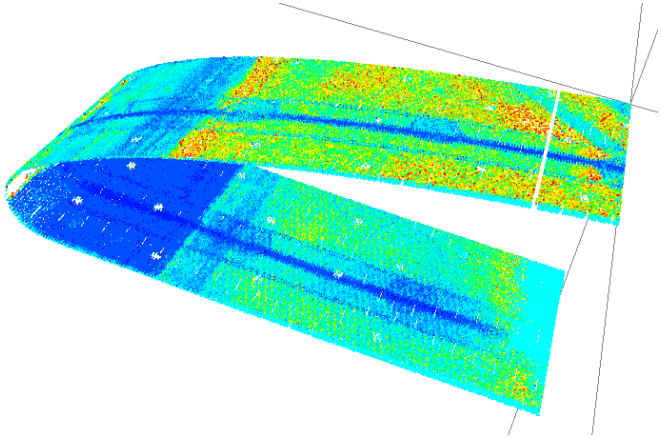
C-scan Time of Flight



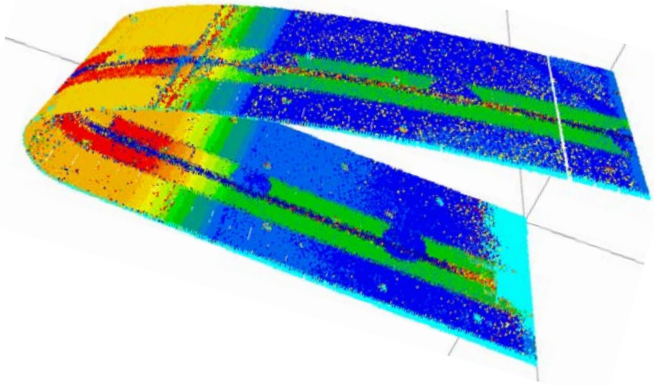
Development of Laser Ultrasonics



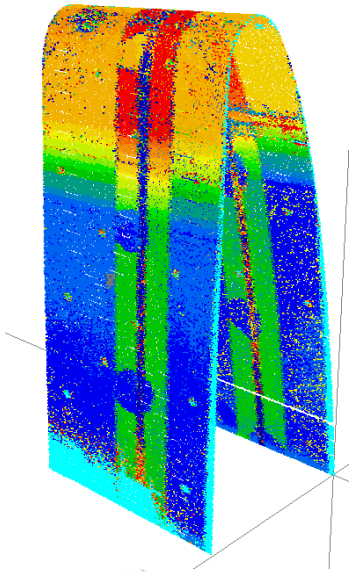
C-Scan Amplitude

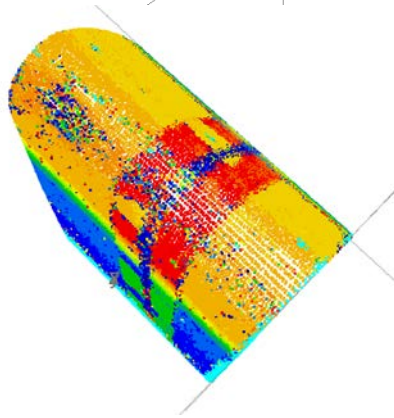


C-Scan Time of Flight



Defects seen at different angles





Thanks for your attention !

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