Comparison of 3 emerging optical NDI techniques on complex shaped composite structures based on carbon fiber

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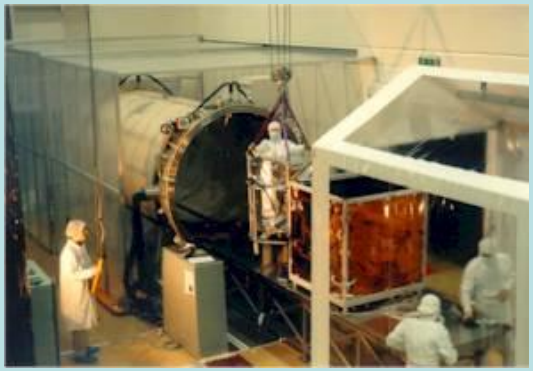
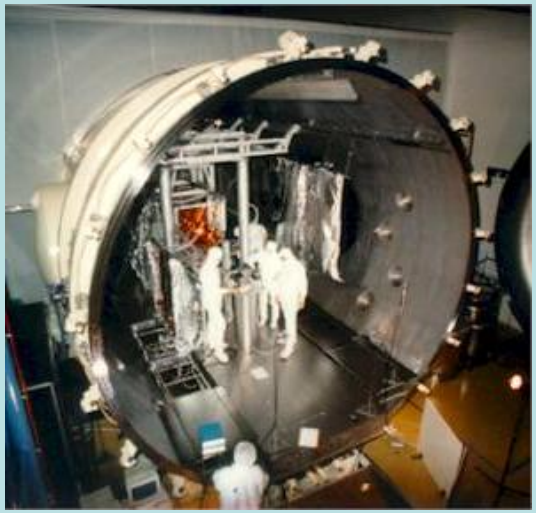
The Space Center of Liege

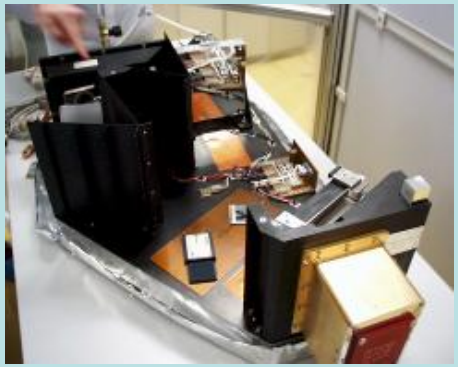
Optics for Space

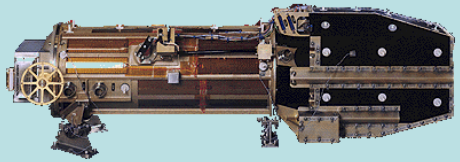
Simulated space environment testing
Large chambers with optical benches





Development of optical
Space instrumentation





esa

NASA

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

CNSA

ISRO
Indian Space Research Organisation
इसरो isro

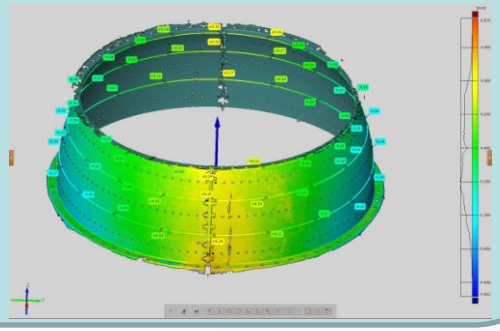
Development of
Advanced Technologies

- 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

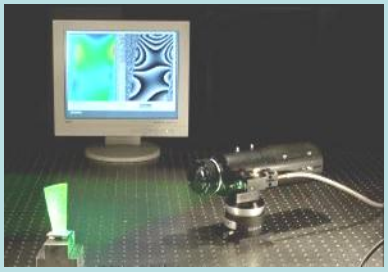
Research in laser and optical metrology and NDT for aerospace

Dimensional measurement
- Fringe projection
- Digital Image Correlation

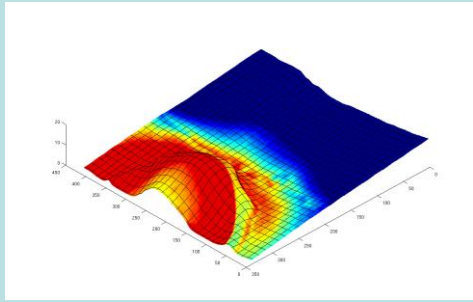


Thermography
- Pulsed + Lock-in
- Vibrothermography (ULg)

Deformation measurement
- Holography
- Speckle interferometry
- Shearography



Combined Speckle-Thermography

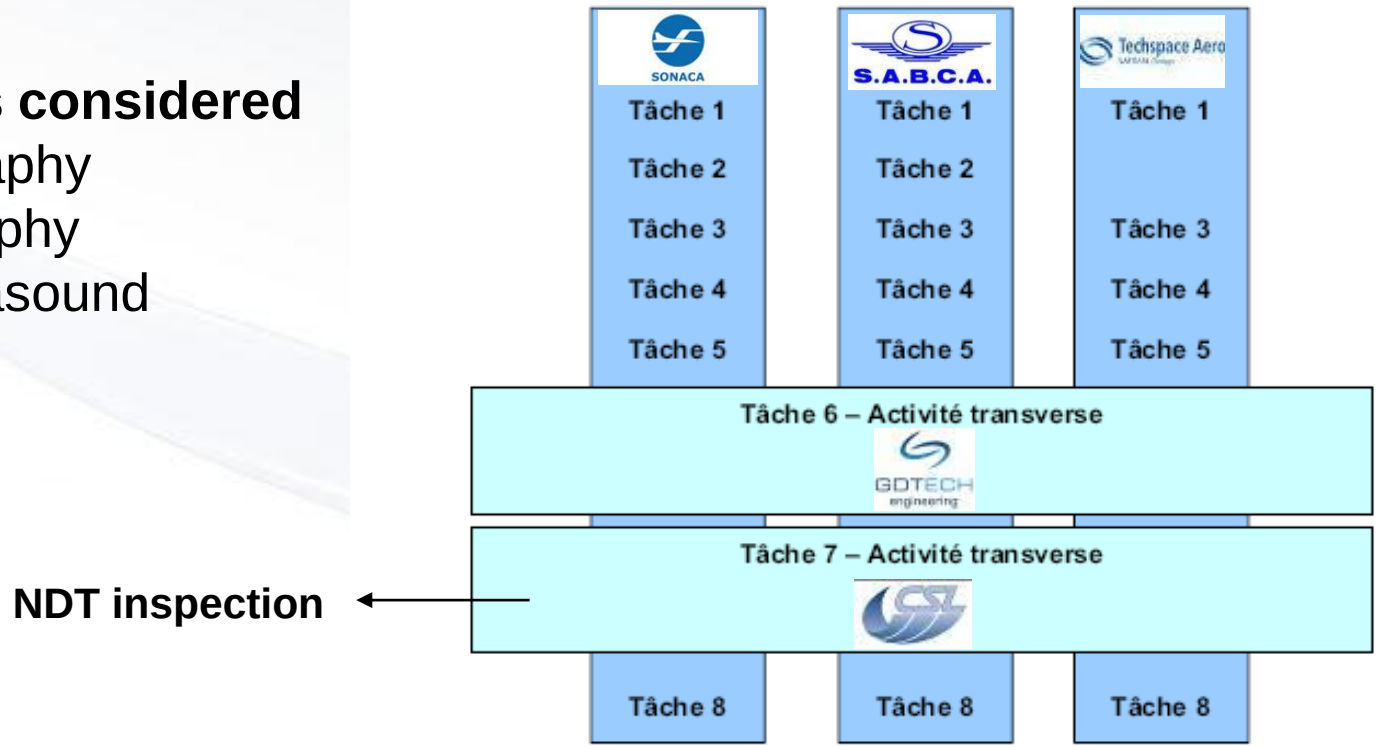


Laser Ultrasonics

Motivation of the study

- **Efficient Composite Technologies for Aircraft Components** (ECOTAC) – Wallonia DG06 – Marshall plan
- Phase 1: benchmarking (2011-2012)
  - Study emerging laser/optical NDT techniques
  - Complex shape aeronautical structures in CFRP

Techniques considered
- Thermography
- Shearography
- Laser Ultrasound



NDT inspection

Partners for NDT

CTA Centre Technologique en Aérospatiale

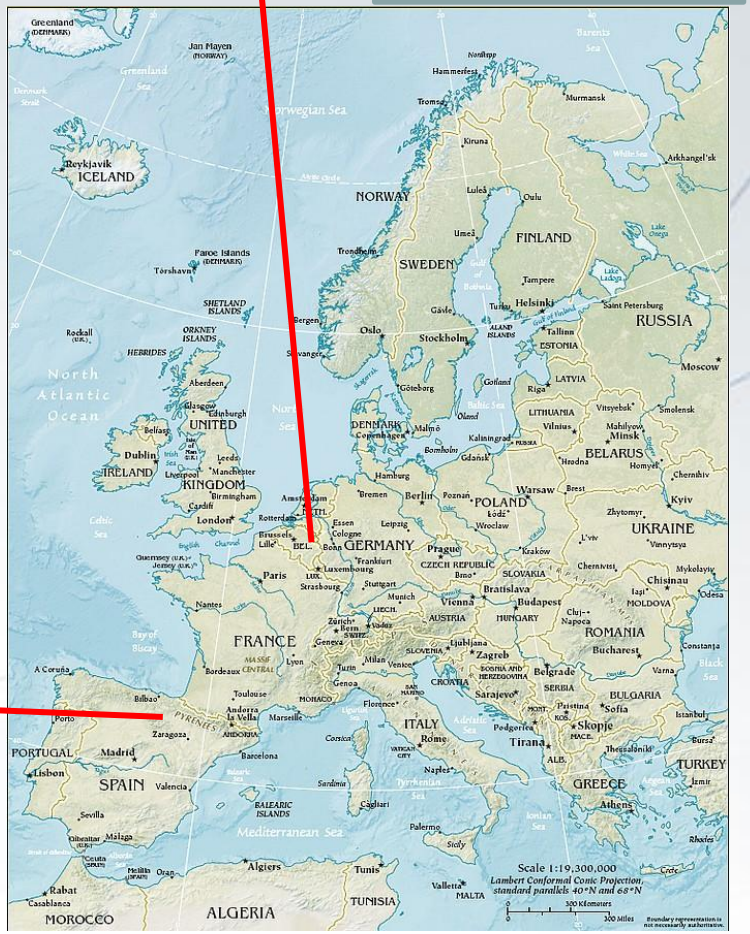
Laser Ultrasound
Thermography
Shearography

TECNAR SENSORS FOR ADVANCED PROCESS CONTROL
CNRC · NRC
visioimage infrared vision systems
UNIVERSITÉ LAVAL

Université de Liège

CSL

Shearography
Vibrothermography

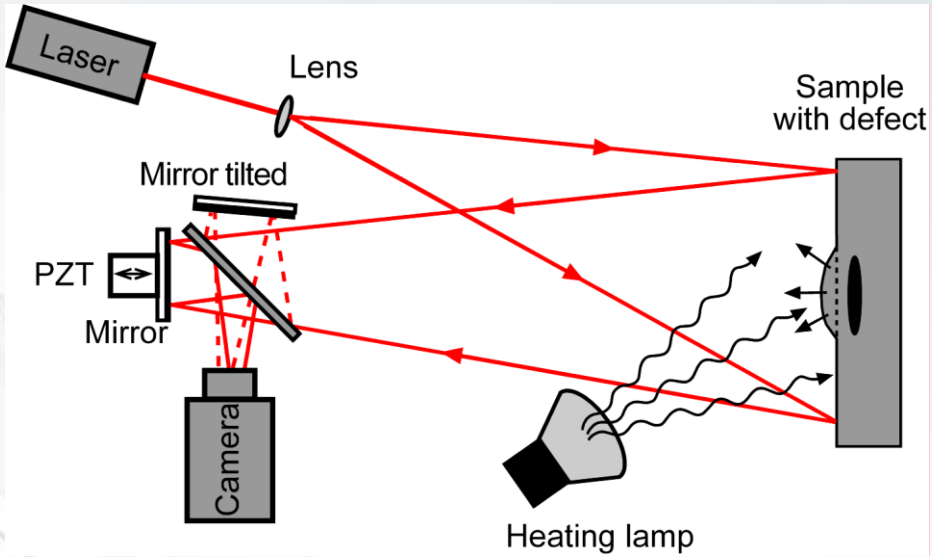


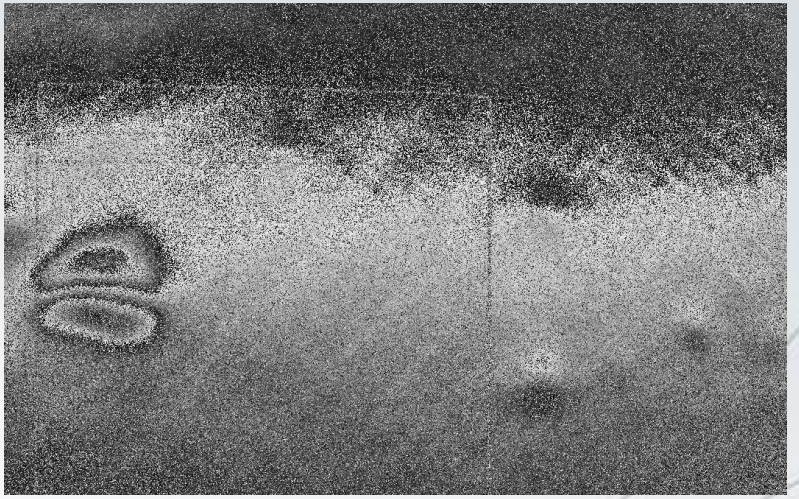
CTA Centro de Tecnologías Aeronáuticas
Aeronautical Technologies Centre

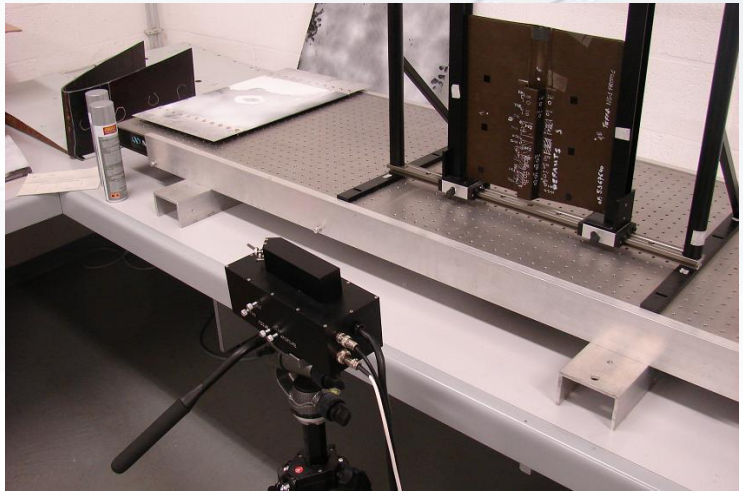
Thermography
Vibrothermography

Techniques used

- Shearography with heating

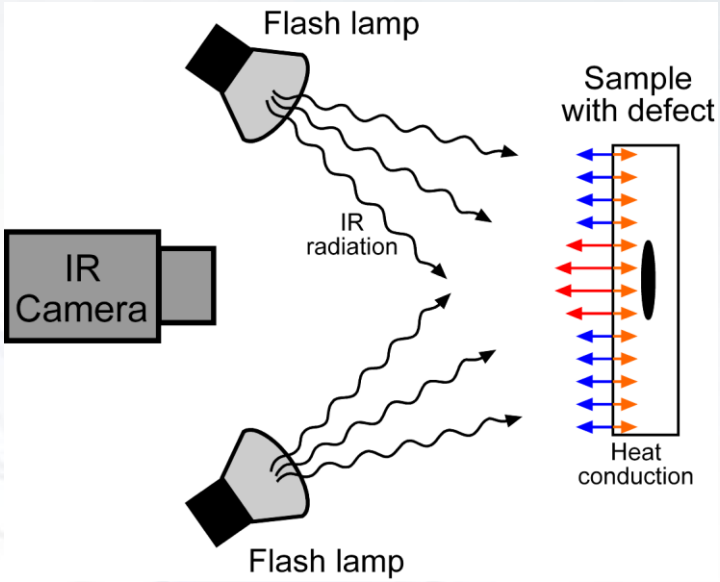


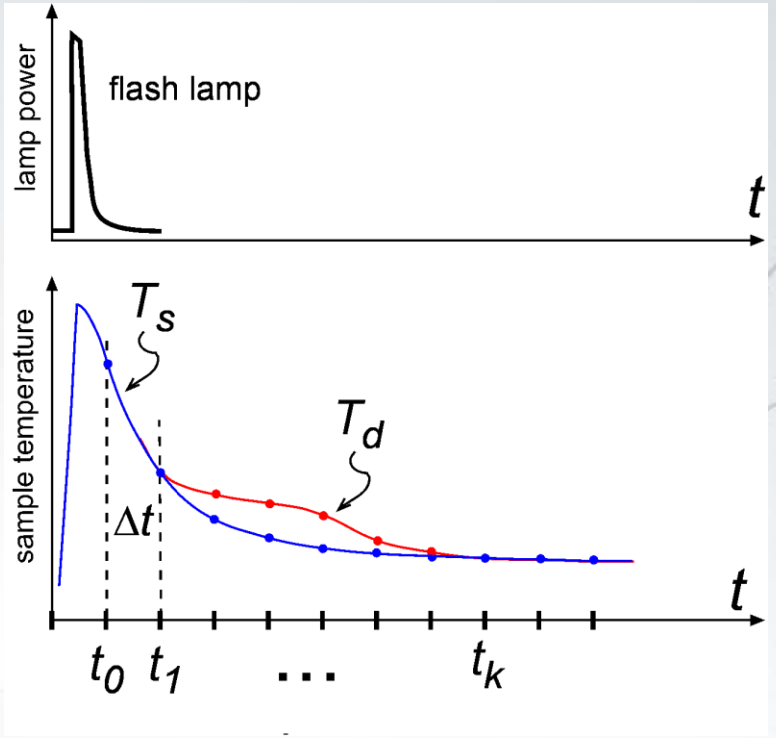




Techniques used

- Thermography : Optical Pulse Thermography (OPT)





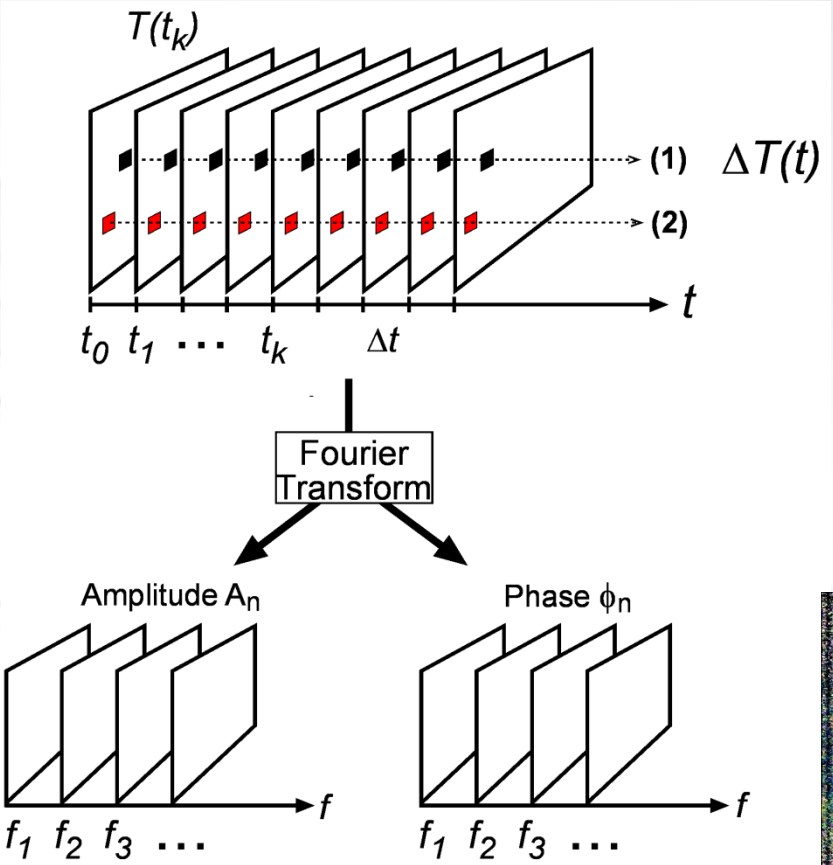
Surface observation of thermal wave and its effect on internal defect

$$t \approx \frac{z^2}{\alpha}$$

The observation time *t* is related to the defect depth
(α : thermal diffusion coefficient)

Techniques used

- Thermography : OPT
  - Pulse Phase Thermography (PPT)



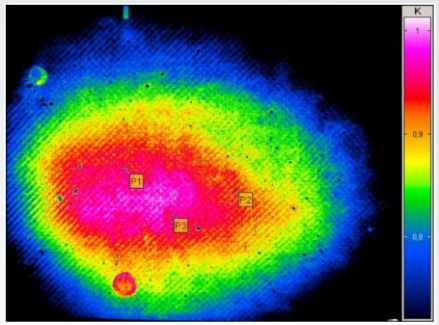


Figure 19: Amplitude image of the PPT analysis

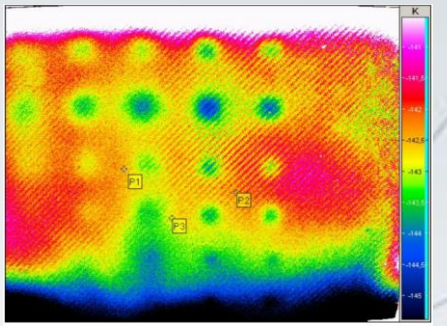
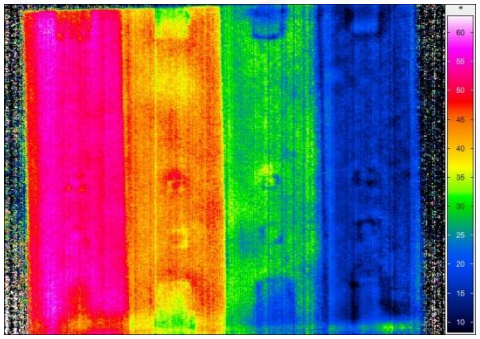


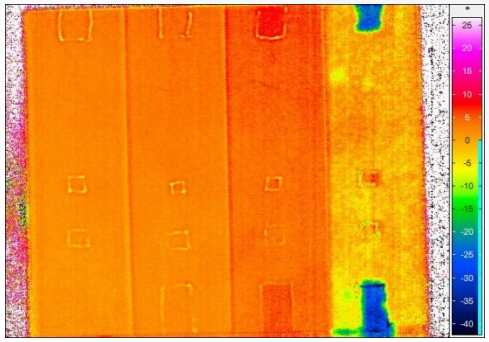
Figure 18: Phase image of the PPT analysis

$$f_n = \frac{n}{N\,\Delta t}$$

f basse (n petit)
t grand
z profond



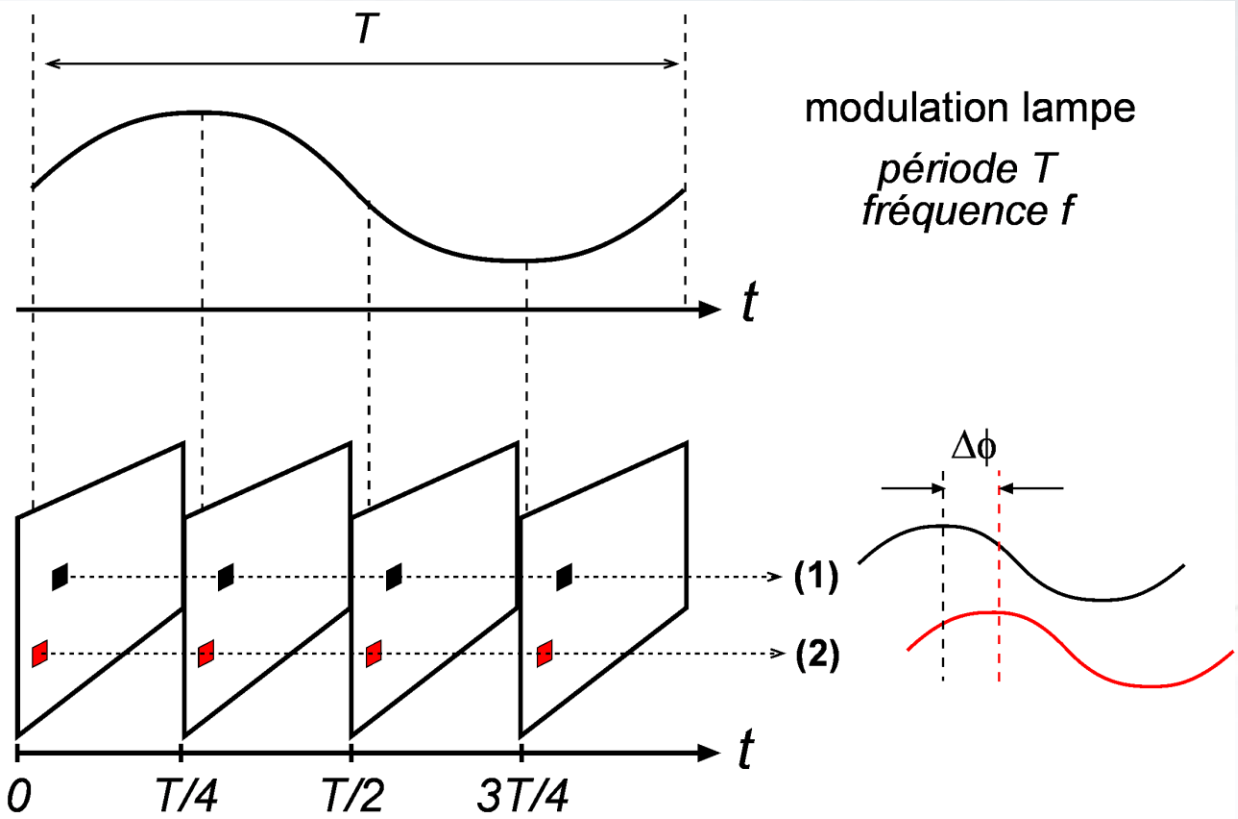
f=0,0125 Hz

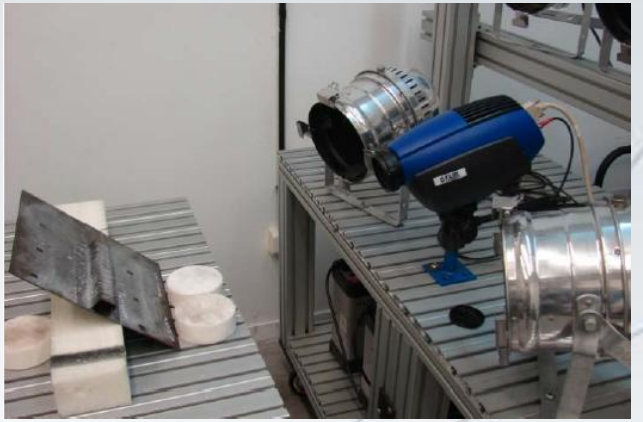


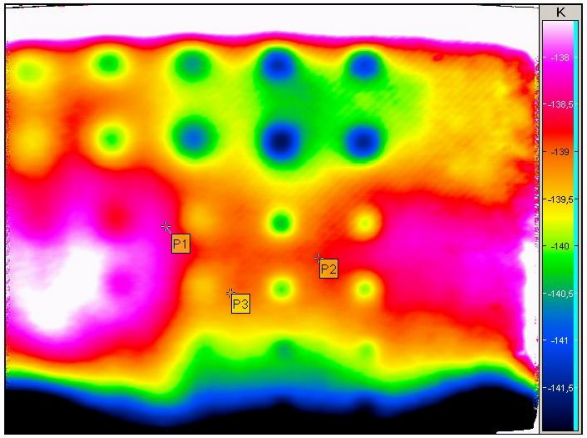
f=0,25 Hz

Techniques used

- Thermography : Modulated halogen + lock-in
  - Optical Lock-in Thermography (OLT)



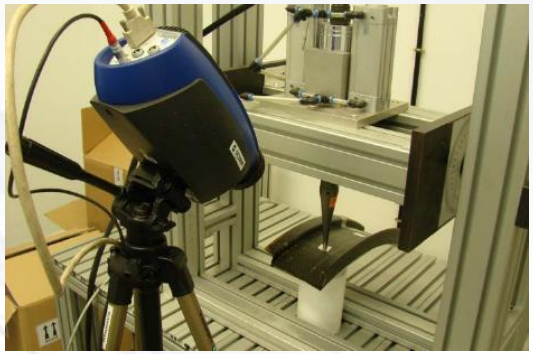


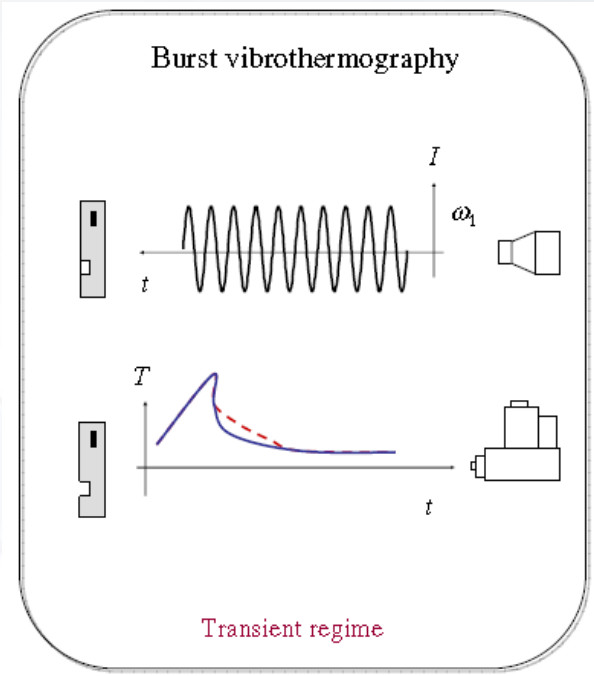


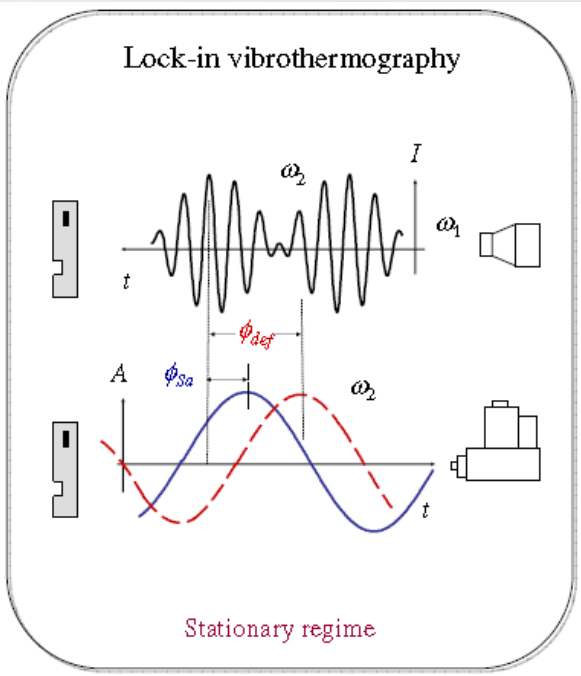
$$\Delta\phi = \tan^{-1}\left[\frac{I(0) - I(T/2)}{I(T/4) - I(3T/4)}\right]$$

Techniques used

- Vibrothermography
  - Ultrasound lock-in Thermography (ULT)
  - Ultrasound Burst Thermography (UBT)



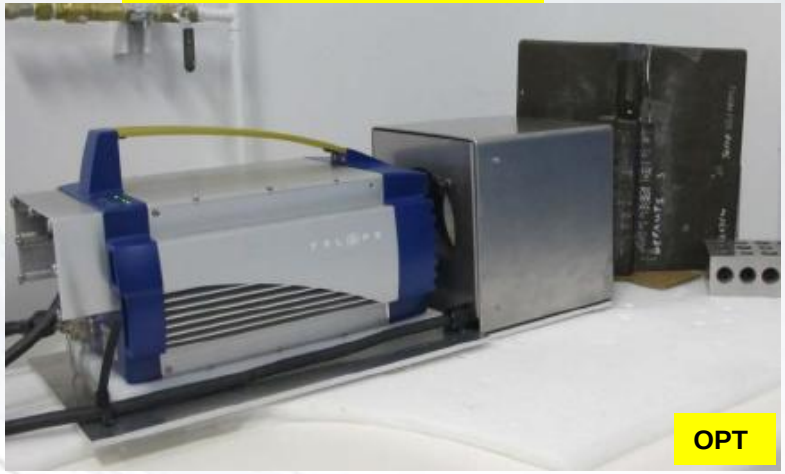




Techniques used

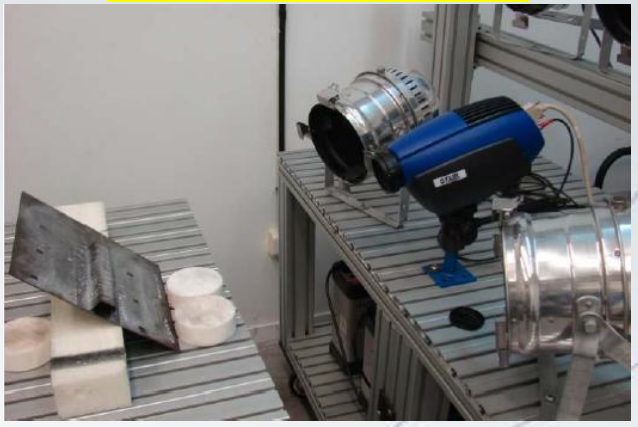
- Thermography investigations

CTA Montreal

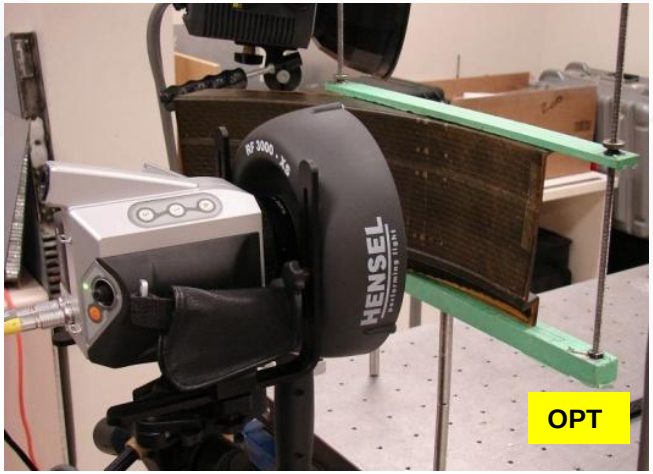


-Cooled cameras
-640x512

CTA Spain



GEL-MIVIM / VisioOImage (Québec)

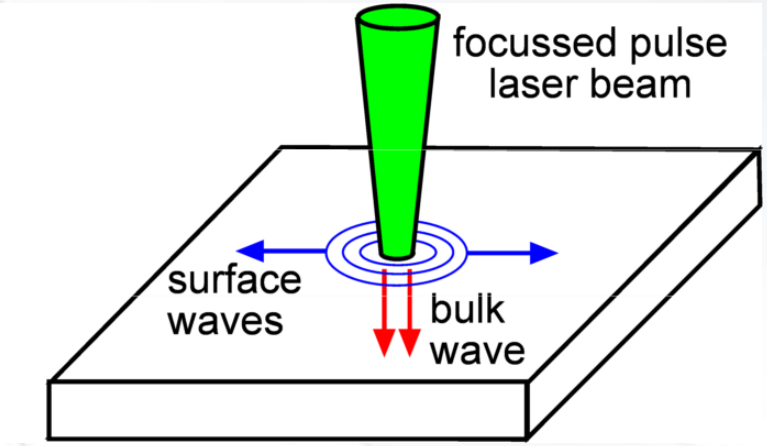


- Uncooled camera
-Jenoptik LWIR
-640x480

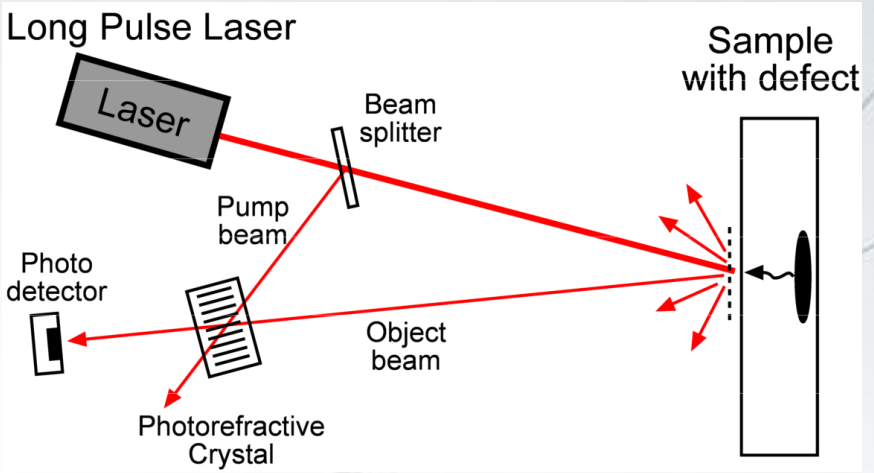
Techniques used

- Laser Ultrasounds

Generation of ultrasound by laser
Thermoelastic effect



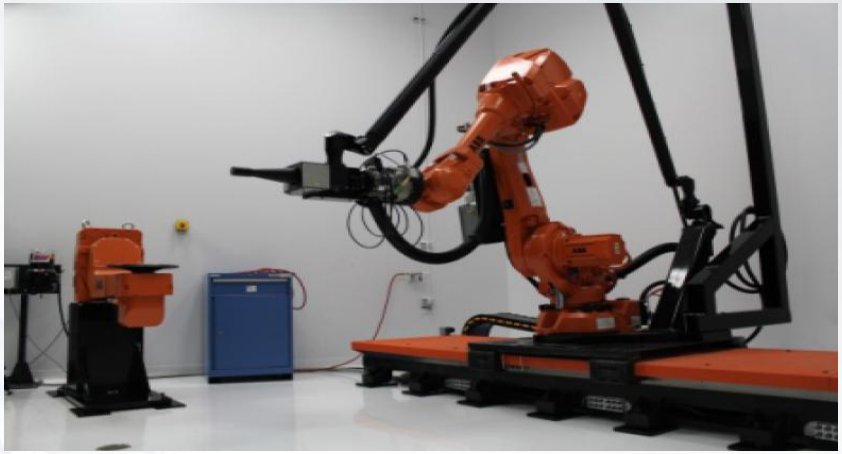
Detection of ultrasound by laser
Interferometric probe (with laser) and Two-Wave Mixing



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

Techniques used

- Equipements used



CTA Montreal

- **Generation : pulsed CO2 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

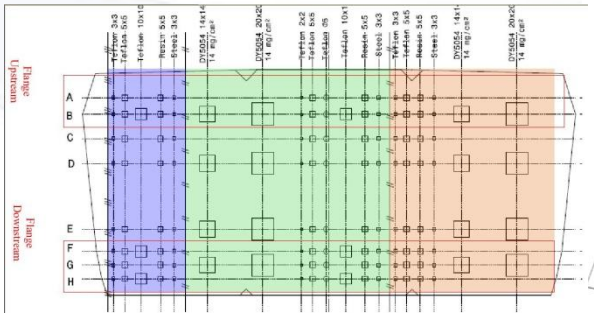
Monolithic samples
Calibrated defects (teflon inserts, flashbreaker,…)

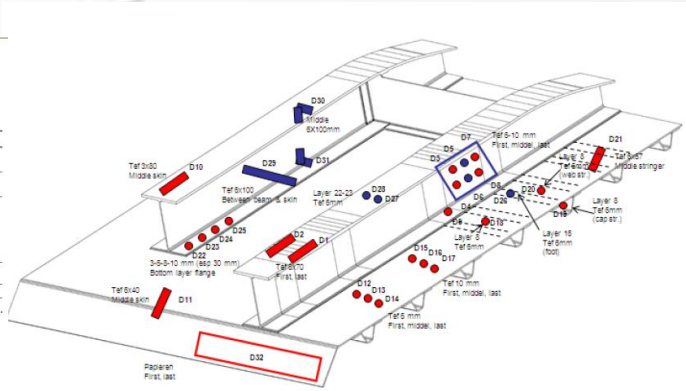
1

3

4

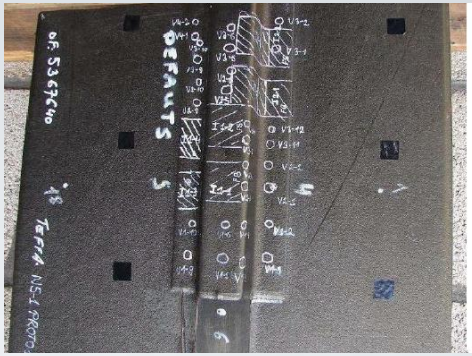
2

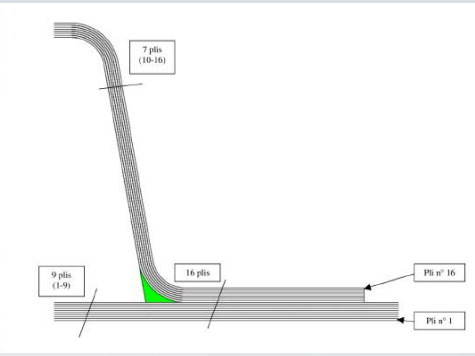


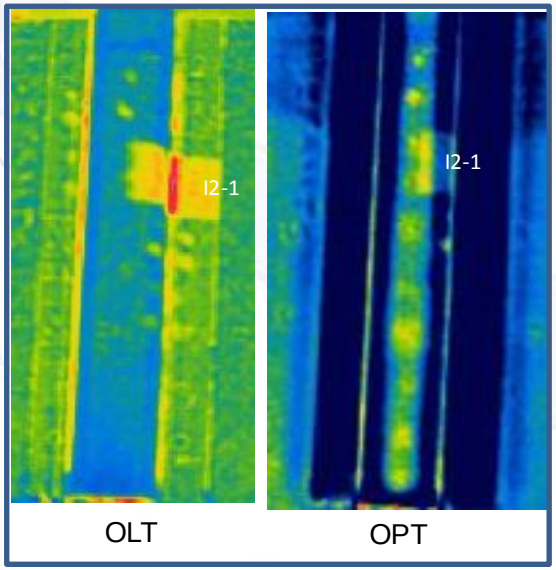


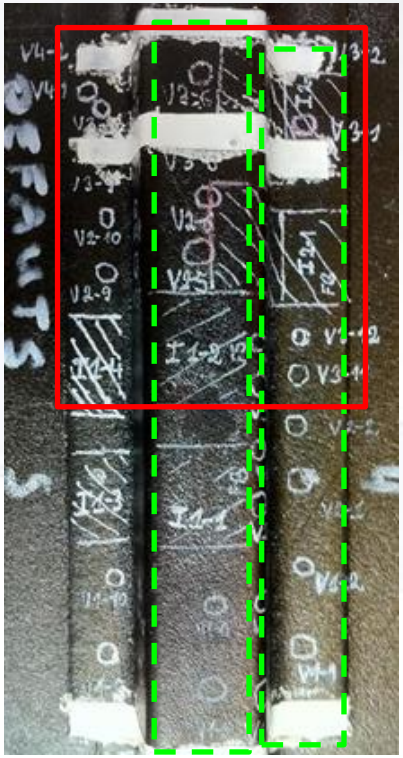
Results

- Sample 1: Comparison

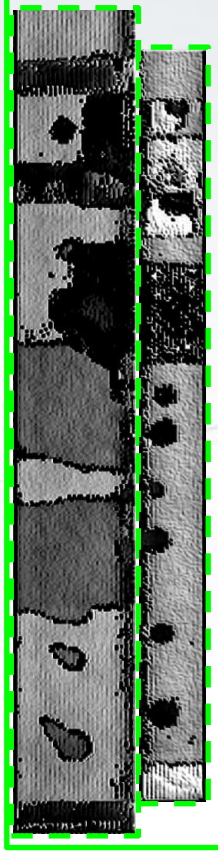








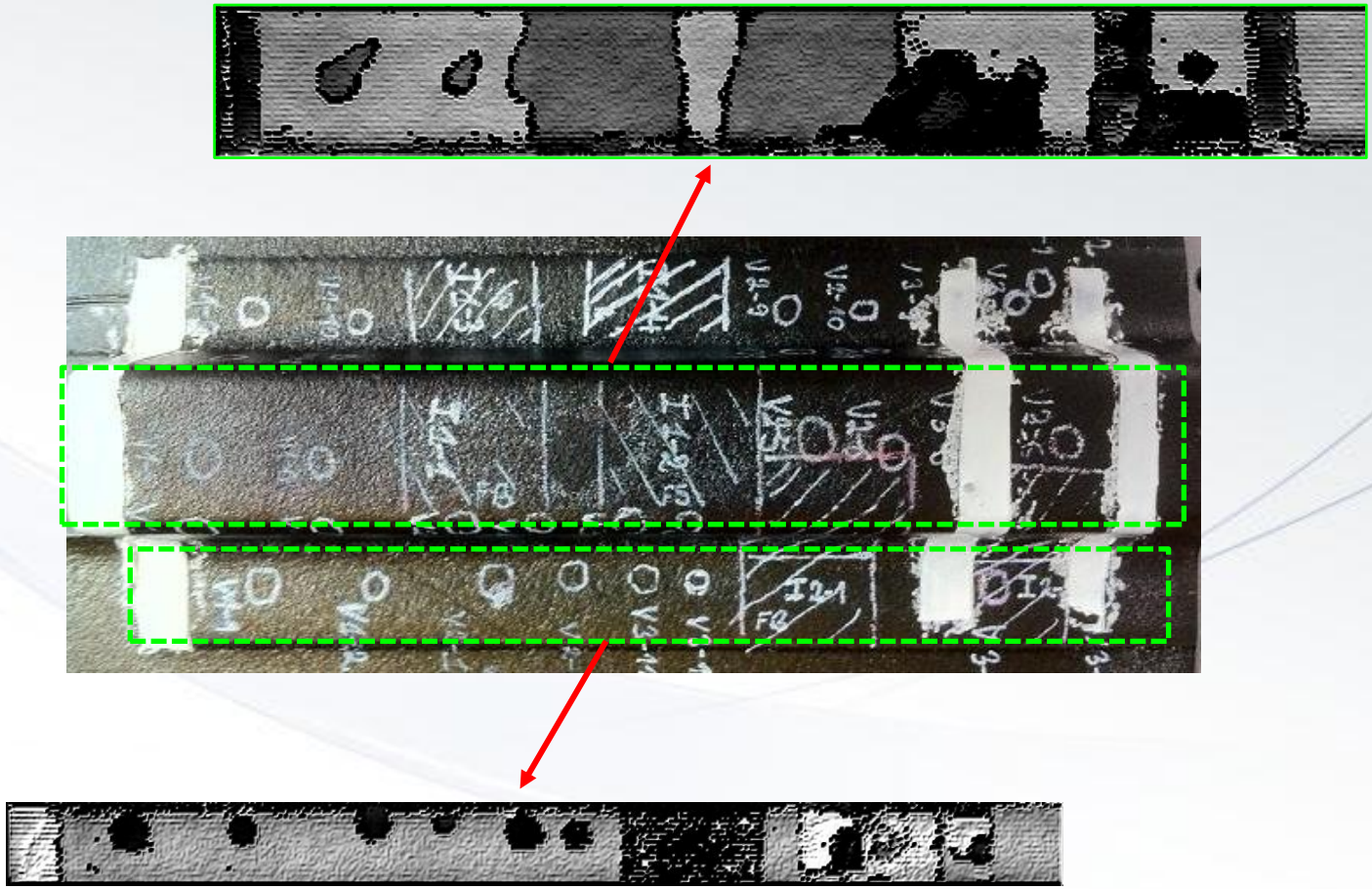
Ultrasons laser



Shearographie

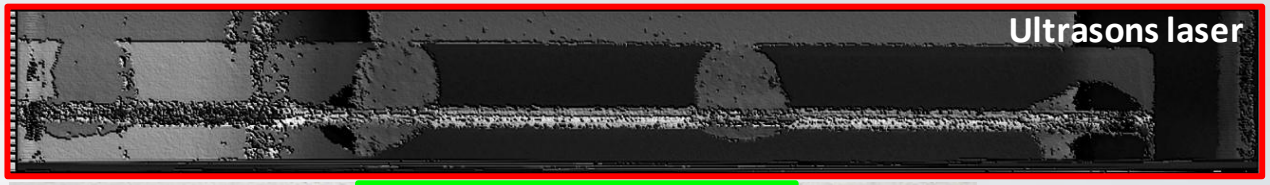
Results

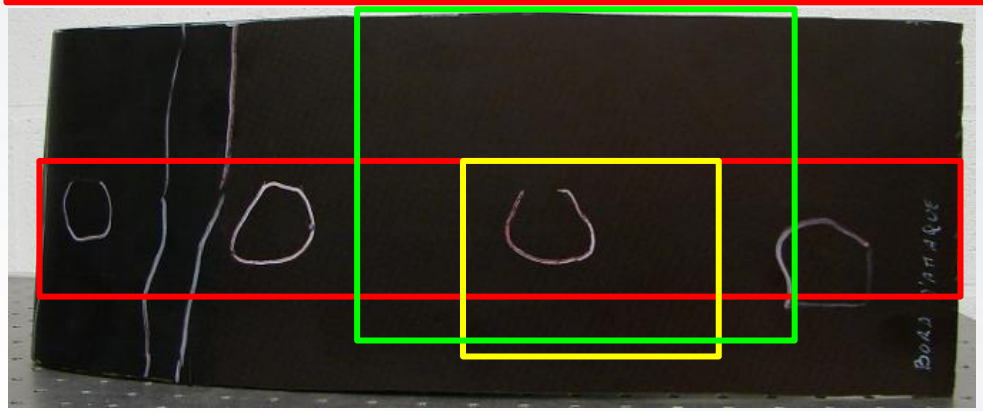
- Sample 1 by Laser Ultrasound



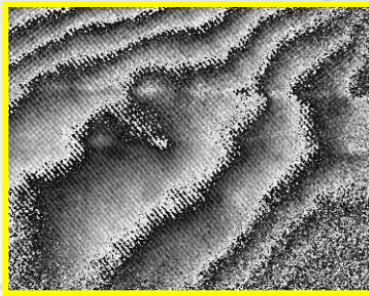
Results

- Sample 2 : Comparison

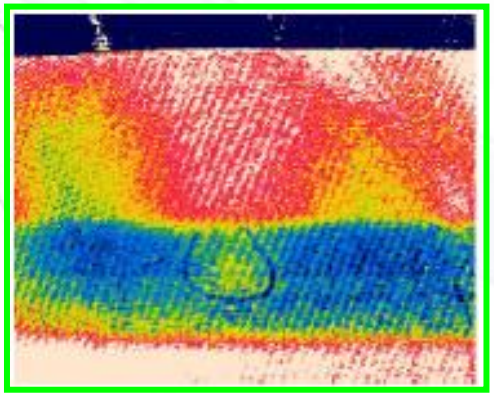


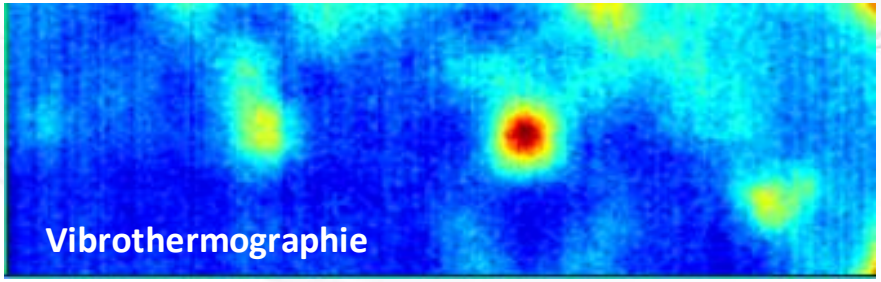


Shearo



Optical pulse thermography

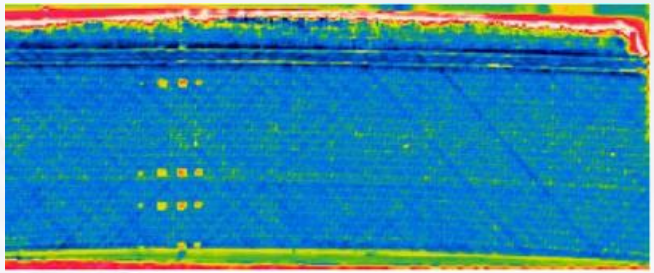




Results

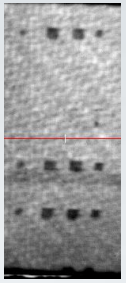
- Sample 3 : Comparison

OLT

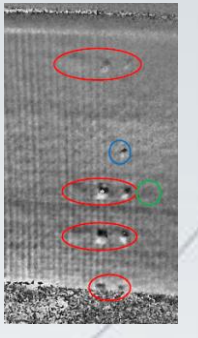


Face concave observée

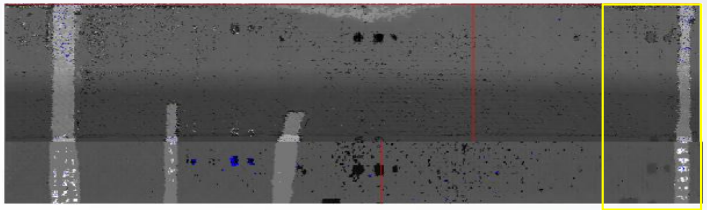
OPT



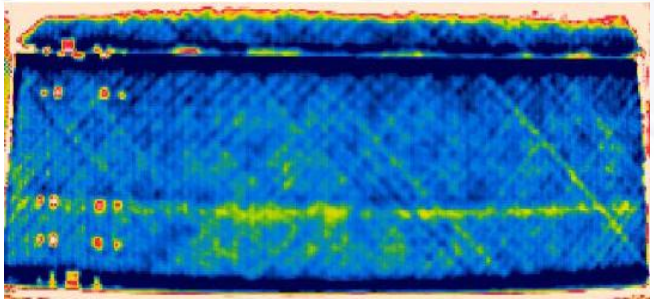
Shearographie



USL

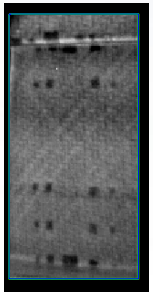


OLT

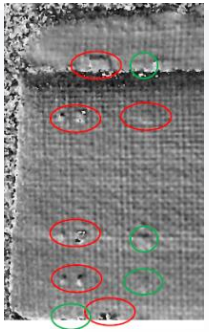


Face convexe observée

OPT

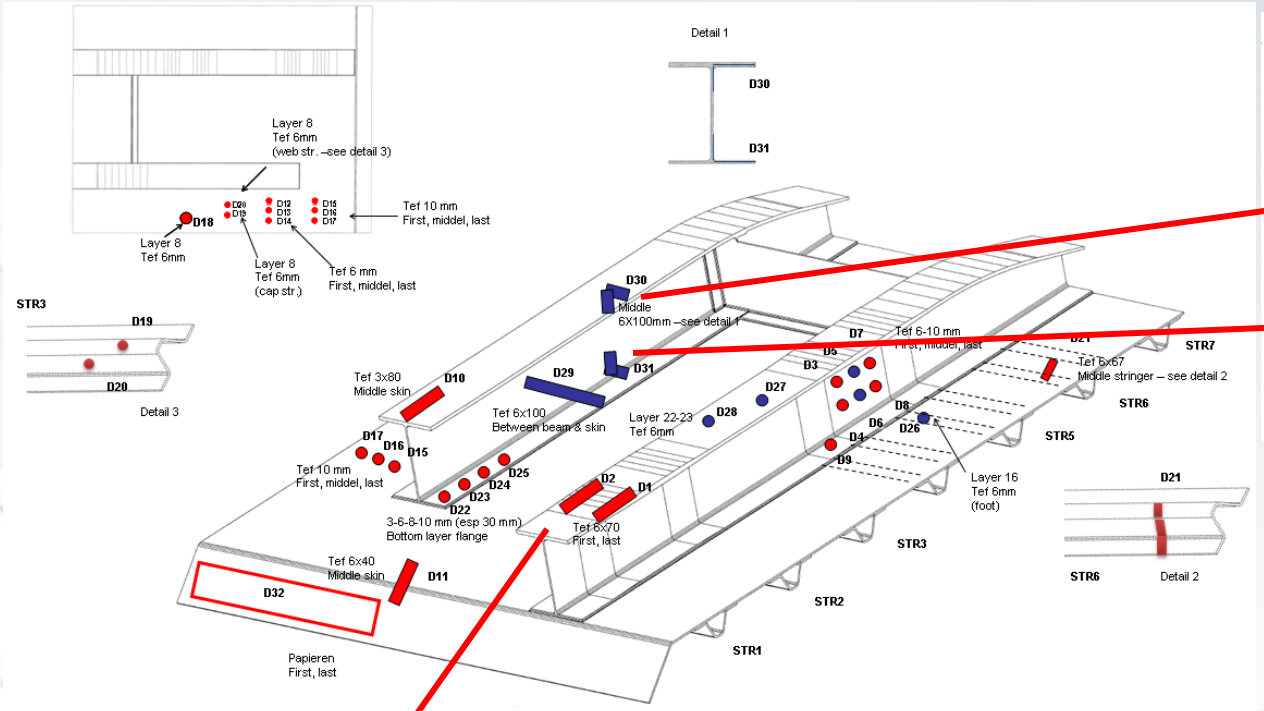


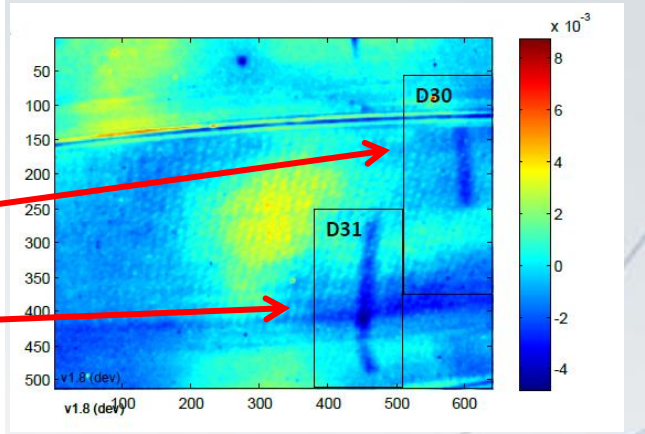
Shearographie

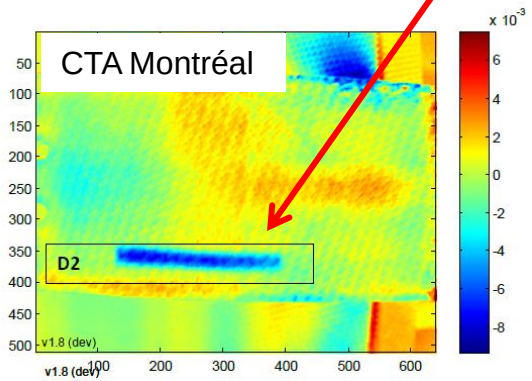


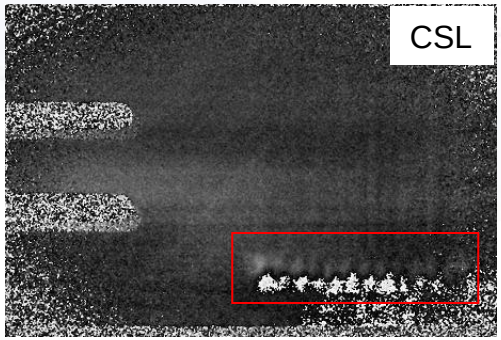
Results

- Sample 4 : Thermography - Shearography



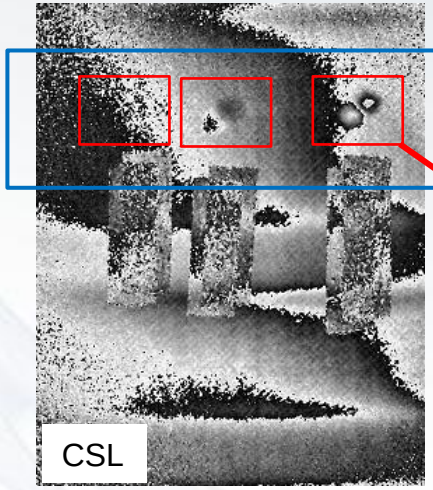




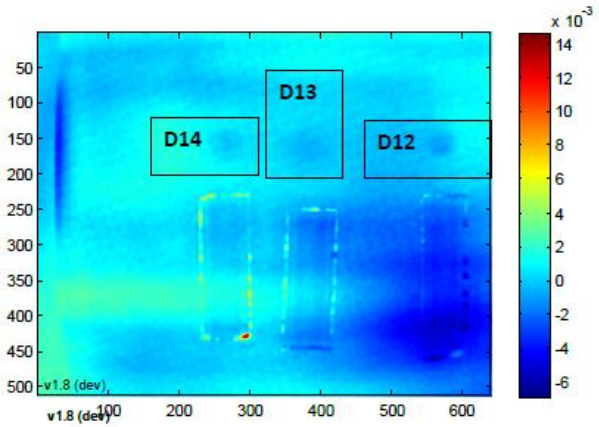


Results

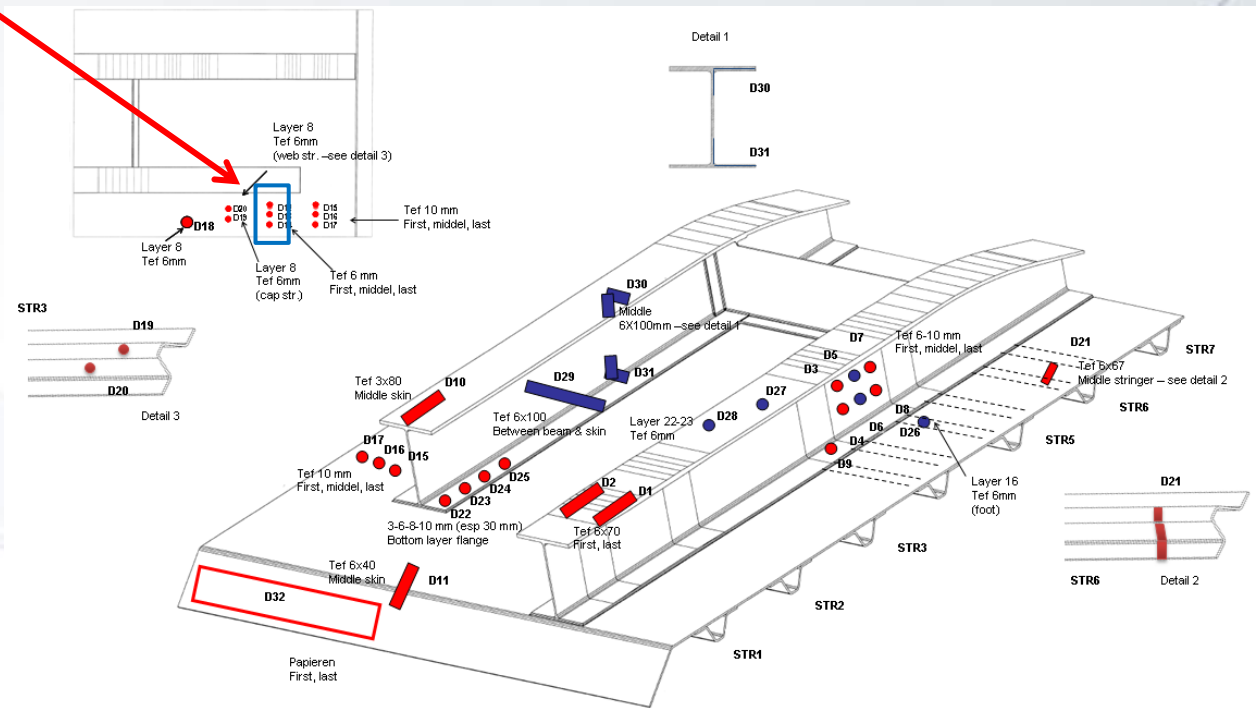
- Sample 4 : Thermography - Shearography



2,4 mm **1,5 mm** **0,7 mm**



CTA Montréal



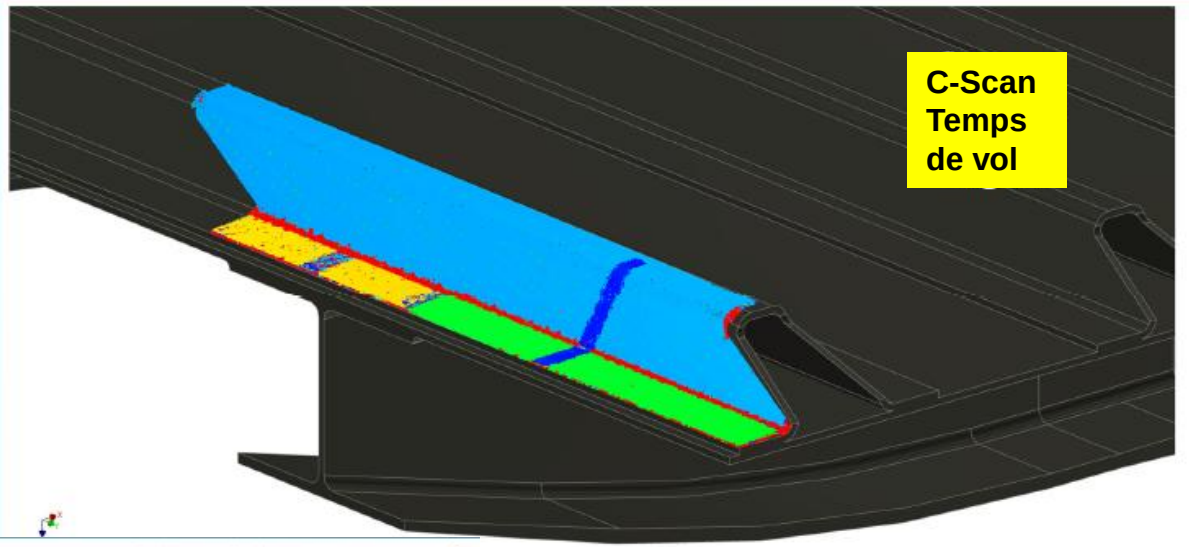
Results

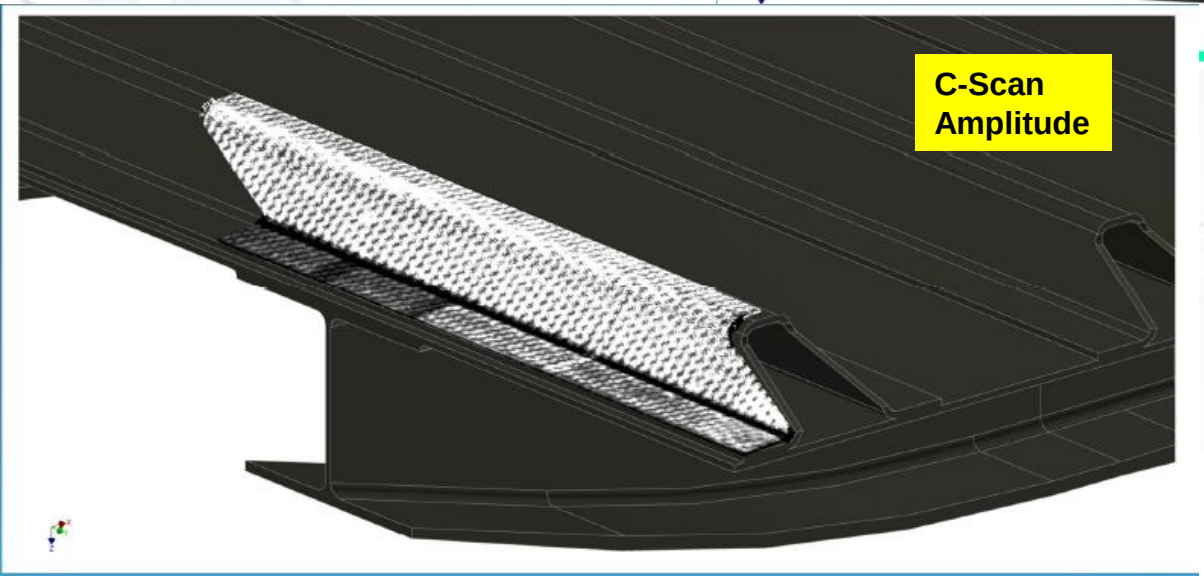
- Sample 4

CTA Montréal

Results

- Sample 4 : Laser Ultrasound





Comparison

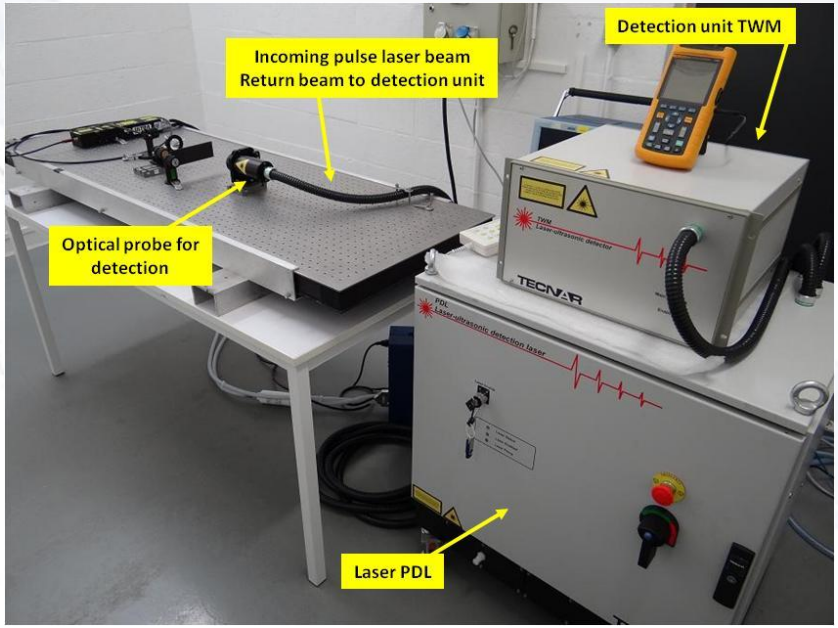
	Thermography	Shearography	Laser UT
Depth	1,5 mm	> 1,5 mm	>>> 1,5 mm
Dimensions	3-4 mm	3-4 mm	2 mm
Interpretation	+	-	++
Measurement	Qualitative	Qualitative	Quantitative
Depth assessment	-	-	++
Set-up	+	+	- (scanning)
Cost	$$	$	$$$$

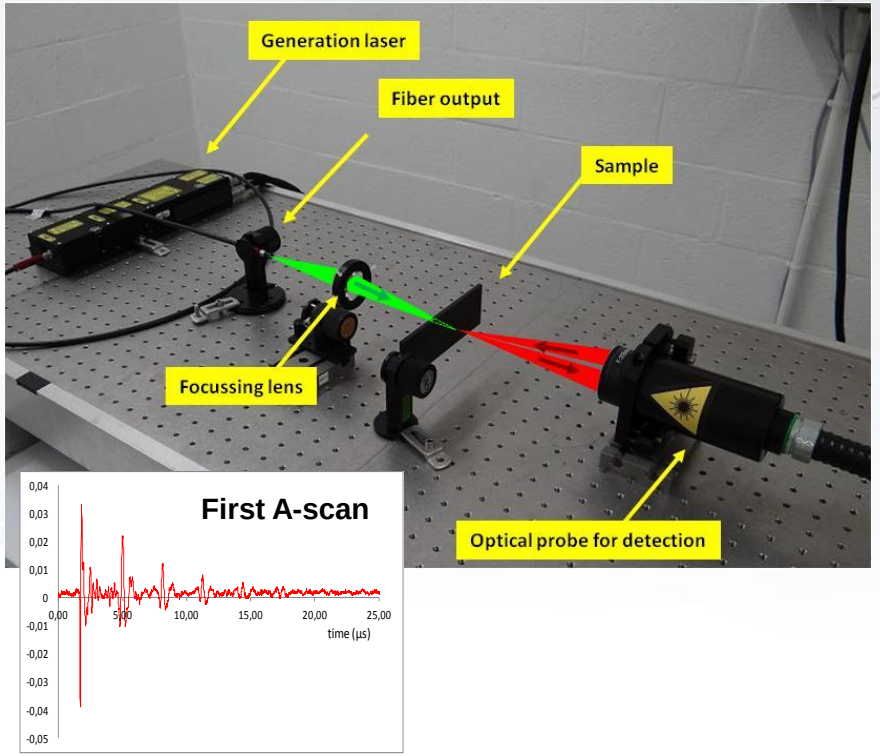
Calibrated Defects are made of teflon to represent delaminations for UT technique
No fast conclusion !

NDT techniques must be envisaged in complementarity

Discussion - 1

- Laser Ultrasound shows high potential
  - Develop this technique in Phase 2 of ECOTAC project
  - Purchase of generation and detection equipments
  - Study combination of both segments
  - Implement robot-arm for scanning complex parts (2014)



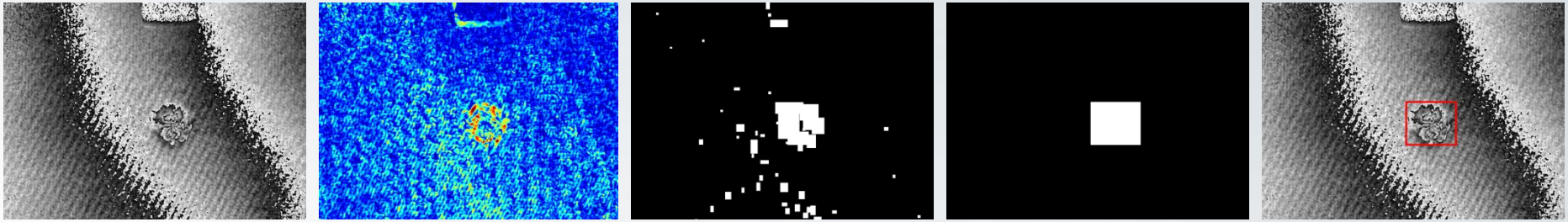


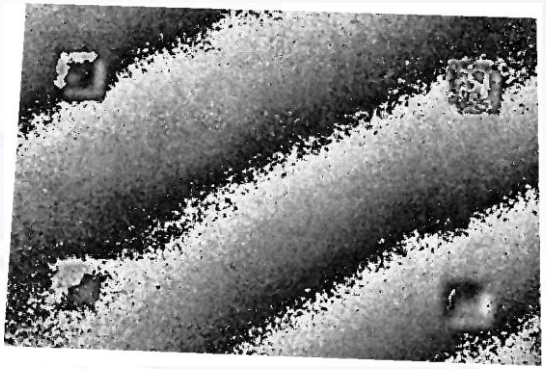
Discussion - 2

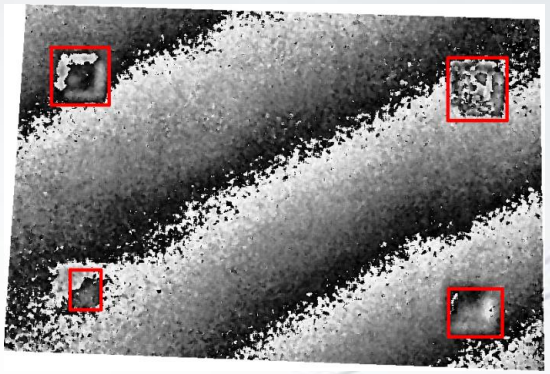
- Thermography and Shearography
  - High potential (full-field – no scanning)
  - Suffer from interpretation
- New projects have started
  - Dimensioning of defects by NDI techniques
    - Thermography - Shearography
    - Scientific collaboration between CTA (Montreal) and CSL
    - Academic projects (Ulg,…)
    - Industrial projects (under evaluation)
  - New post-processing applied to shearography for easier interpretation
    - Dé-Composit project
    - Wallonia, DG06 (Cwality program)
    - Optrion S.A.

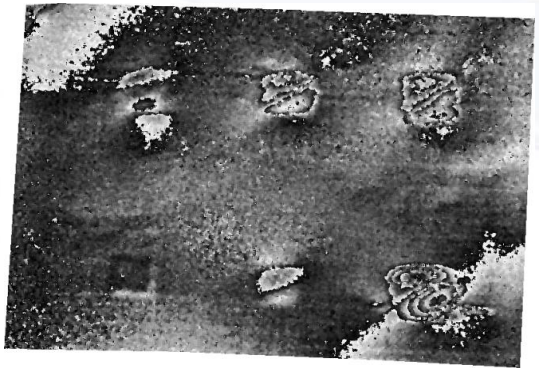
New developments

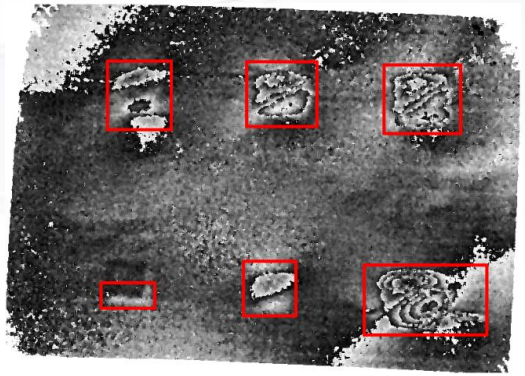
- Shearography : automated detection









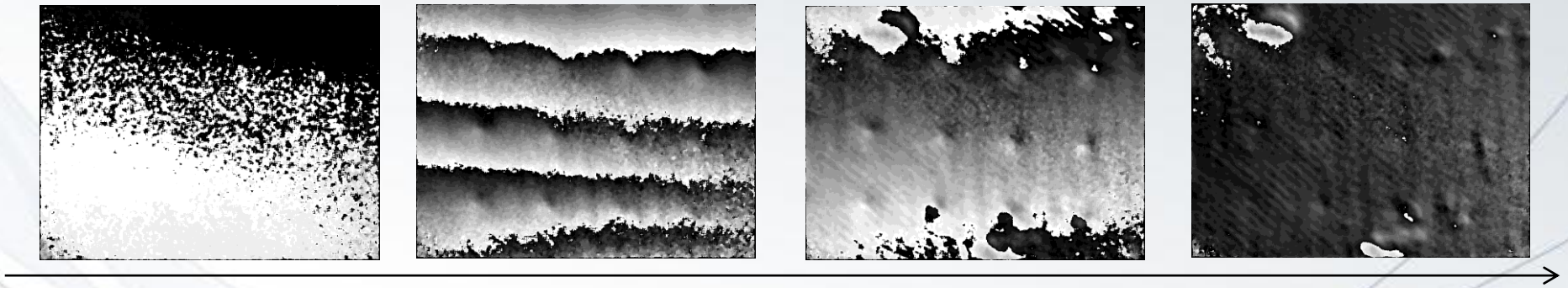


New developments

- Shearography : ease of interpretation

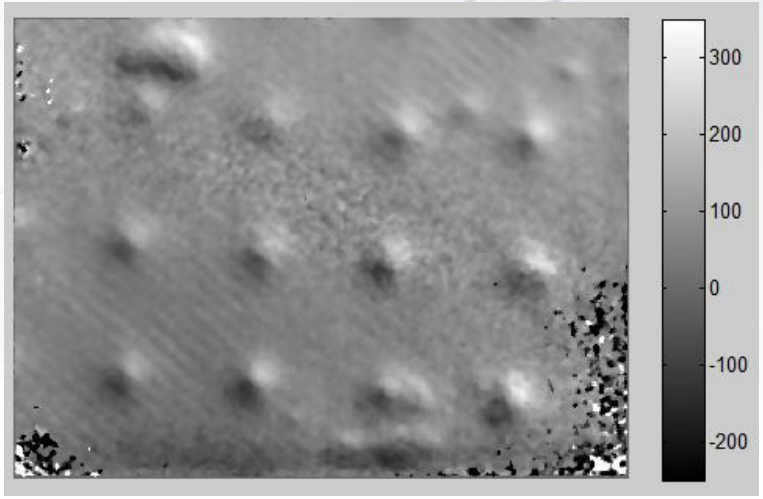
  Temporal sequence shows various defects at different instants

  Heat wave travelling through the sample



New post-processing provides

- A single image
- With all defects
- Same visibility of defects independent of depth



The Future

- R&D of optical-laser NDT-NDI techniques
- Composite thermo-mechanical characterization (dilatation, etc…)
- Collaboration with research center and industries
  - Materials
  - Simulation
  - NDT-NDI
- Lectures
- Service to industry
- ***Maybe with you?***

Thanks for your attention !

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