Health Monitoring Systems

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Appendix H

ONERA

Outline

1) some health systems studied at ONERA

2) example 1 : HMS for carbon epoxy plates

3) example 2 : HMS for sandwich plates

4) example 3 : HM using electromagnetic fields

5) example 3 : corrosion detection

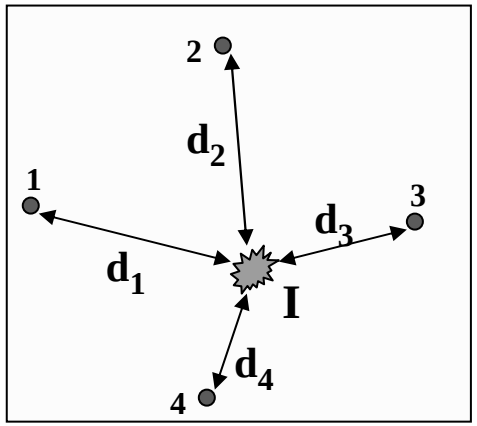
6) Conclusions

Systems studied at ONERA

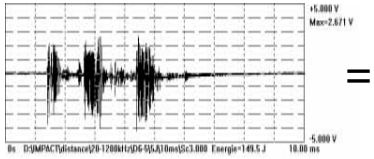
H.M.S. systems studied for

1) impact damages in carbon epoxy plates
   (Lamb waves)
2) impact damages in stiffened carbon epoxy plates
   (Lamb waves)
3) impact damages in sandwich plates
   (Lamb waves)
4) impact, burning and ingress damages in composite plates
   (integrated electromagnetic network)
5) corrosion in metallic plates (PHD thesis)
   (Lamb waves)
6) smart patches for metallic structures
   (PZT devices)
7) participation to BASIMA (European contract)
   (optical fibers)

Health Monitoring for carbon-epoxy plates



Impact => Delamination => Acoustic Source A_s in I

Sensors  **=> Complex Signals $s_k(t)$**

retained information : signal energies $\langle s_k \rangle^2$

<u>Source Identification</u> : Find (A_s, d_k) which minimizes $\Sigma_k \left(A_s/d_k - \langle s_k \rangle^2\right)^2$

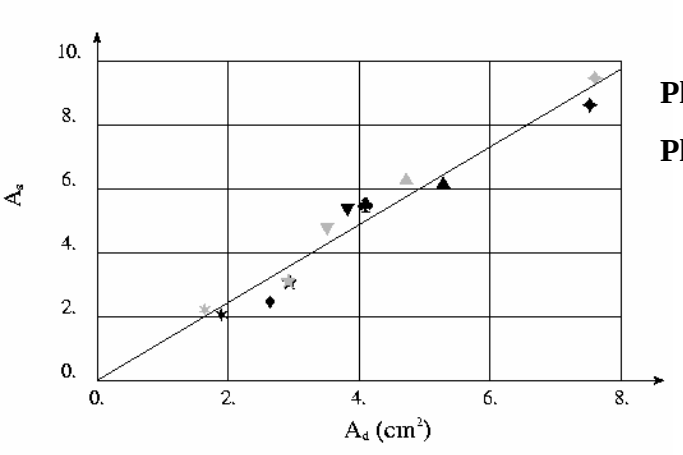


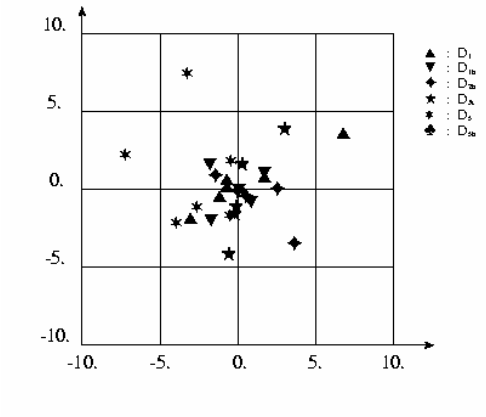
Plate 1 : #

Plate 2 : #

Amplitude A_s / Delaminated Area

d_{ave} = 2.7 cm

σ_d = 2.1 cm



Source Localization / De laminated Area

Health Monitoring for stiffened carbon-epoxy plates

Extension of the method for non stiffened plates to stiffened plates was not successful :

1) no simple correlation found between the energy of the signals and the distance from sensors to impact location

2) too many reflections of waves in the stiffened plate

Health Monitoring for sandwich plates

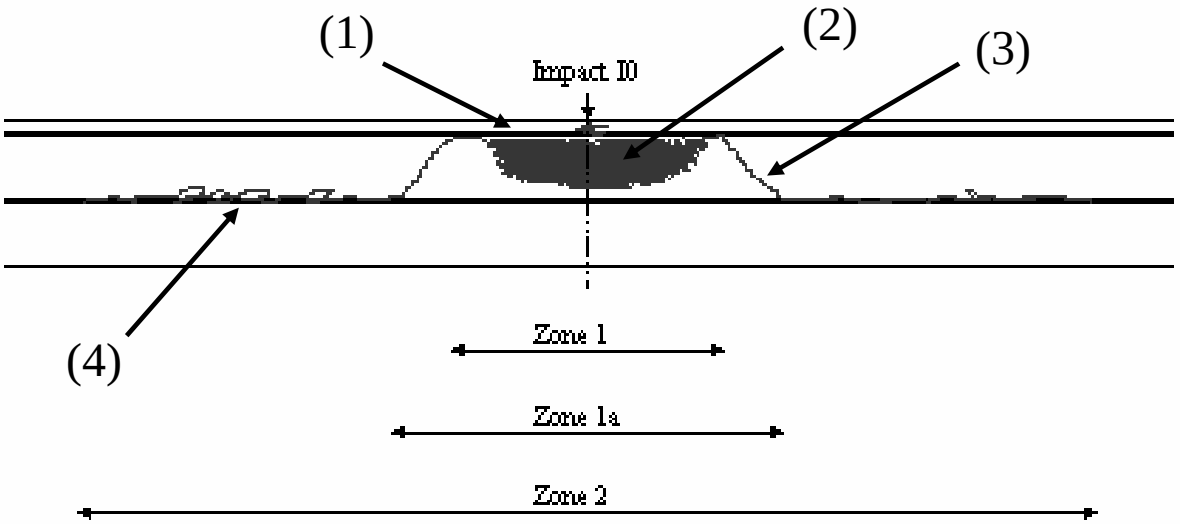
The sandwich structure (radomes)
Non-symmetric structure
Foam core

→ { Very heterogeneous structure => complex dispersion curves
High sensitivity to low velocity impact
High attenuation

=> use of flexural wave in low frequency range

Health Monitoring for sandwich plates

Impact damages



→ **Small debonding of the thin skin (1)**

→ **Crushing of the foam under the impact point (2)**

→ **Transverse crack in the foam (3)**

→ **Large annular debonding of the thick skin (4)**

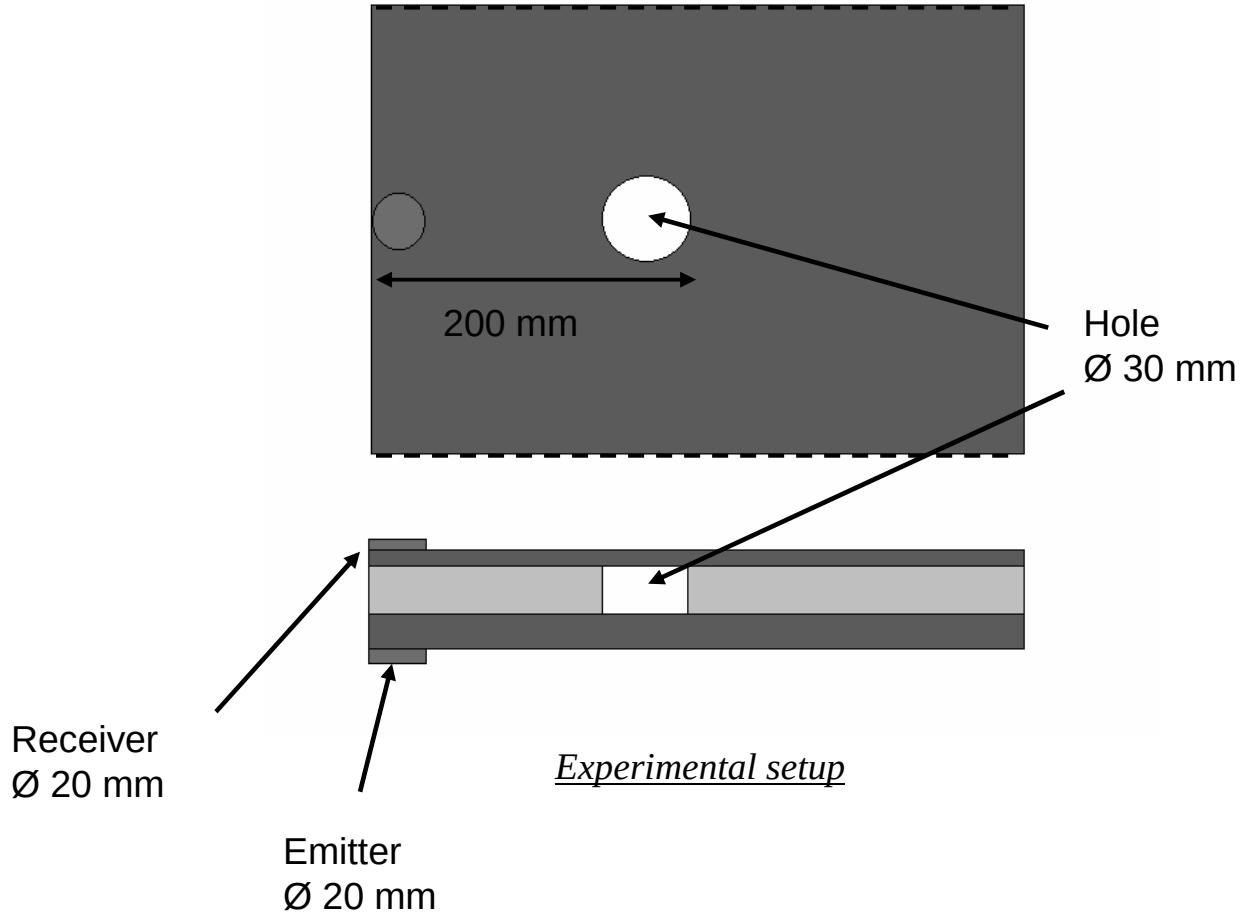
Health Monitoring for sandwich plates

System for calibrated defects

→ **Emitter bonded to the thick skin**

→ **Receiver bonded to the thin skin**

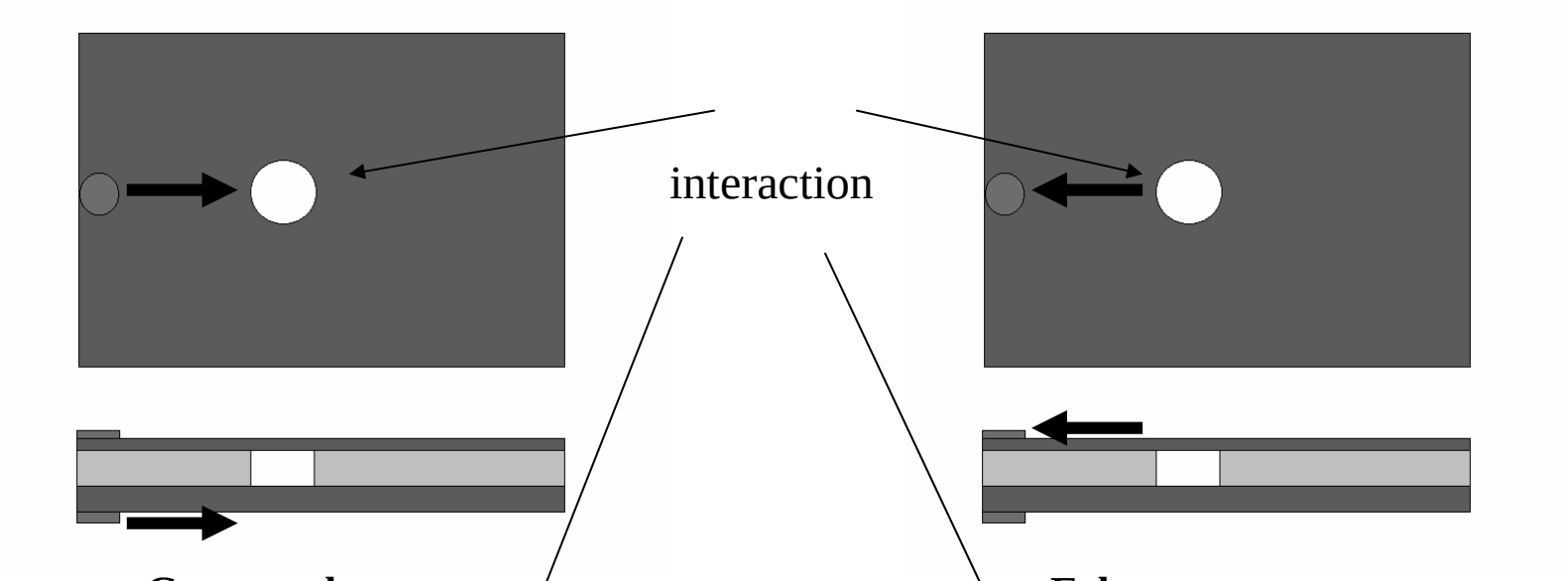
→ **The devices are bonded near the edge of the plates**



Experimental setup

Health Monitoring for sandwich plates

Interaction of flexural waves with damages



def_calibre.wmv

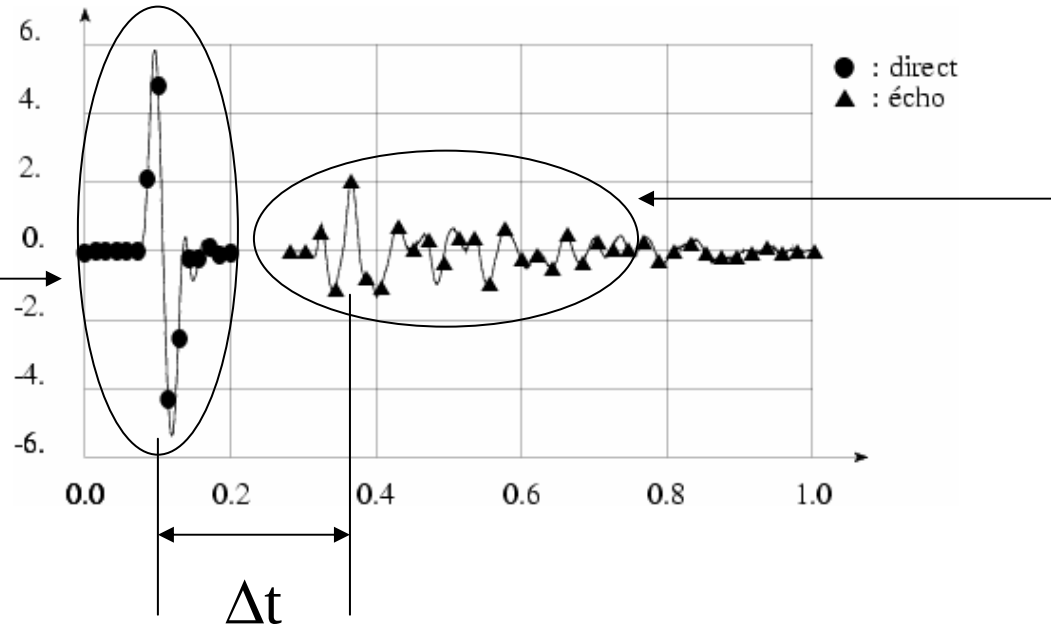
dom_imp.wmv

Interaction for a calibrated defect

Interaction for a real damage

Health Monitoring for sandwich plates

Interaction of flexural waves with holes in the foam



direct signal

echo signal (magnified)

auto-correlation

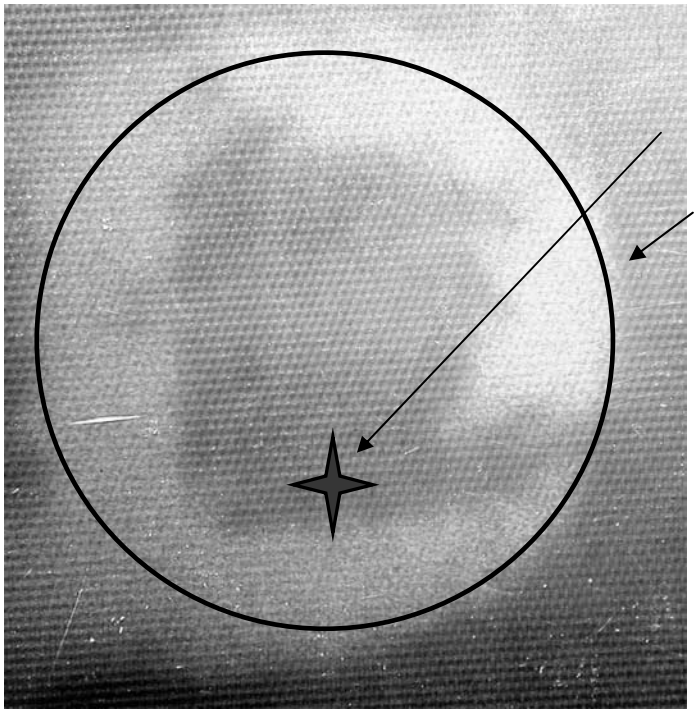
estimation of the size of the hole

estimation of the distance from the transducers to the hole

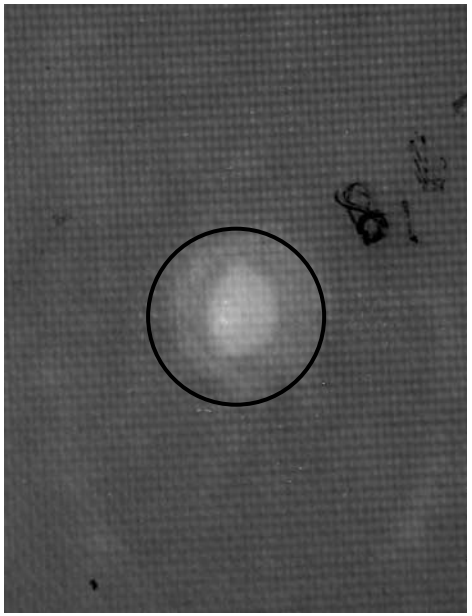
Health Monitoring for sandwich plates

Results for an impact damage (8 J)

- estimated distance : 9,5 cm (average) real distance : 12 cm
- estimated size : between 7 to 8 cm real size : 7,5 cm



Picture 1 : Thick skin



Picture 2 : Thin skin (x2)

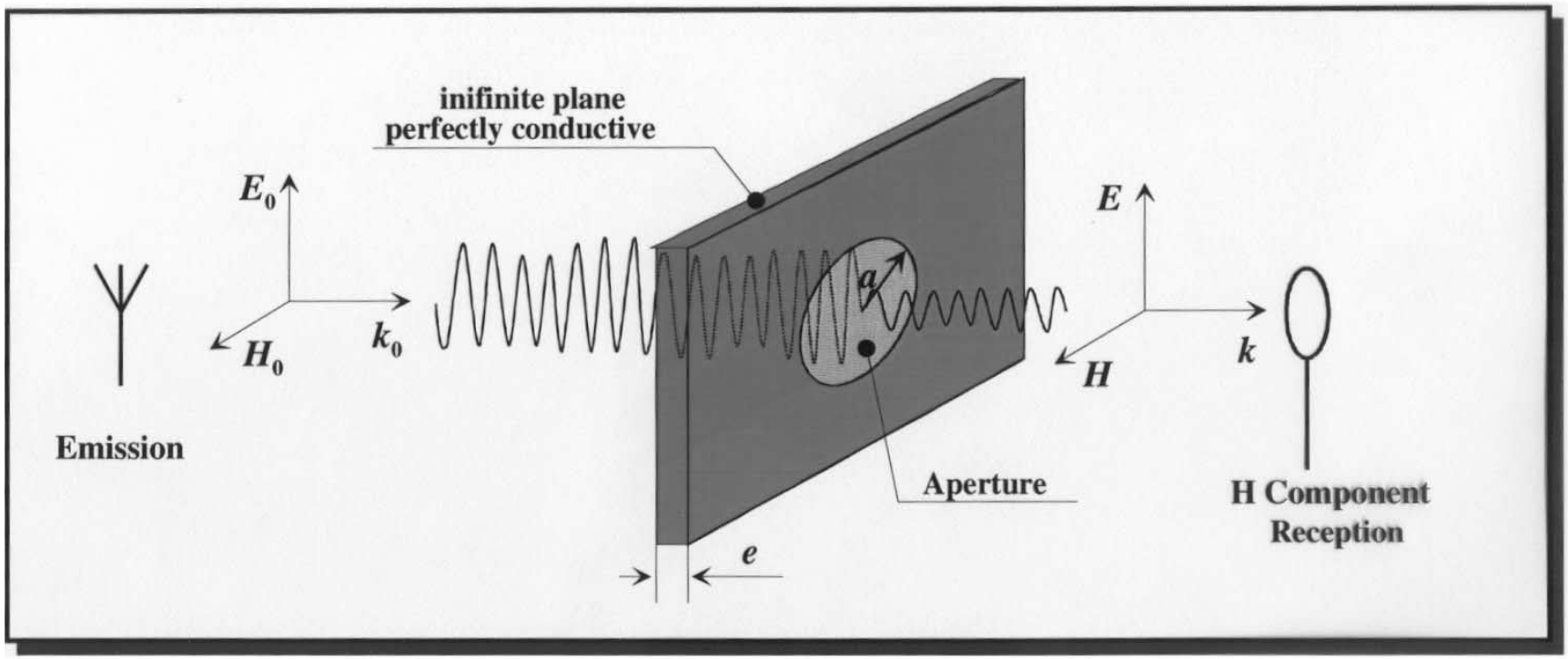
Health Monitoring using electromagnetic fields

ELECTROMAGNETIC STRUCTURAL HEALTH MONITORING

ELECTROMAGNETIC BEHAVIOR OF COMPOSITE MATERIALS (i)

Model from K. F. Casey 1981)

- Skin effect negligible
- Small aperture compared to wavelength



Health Monitoring using electromagnetic fields

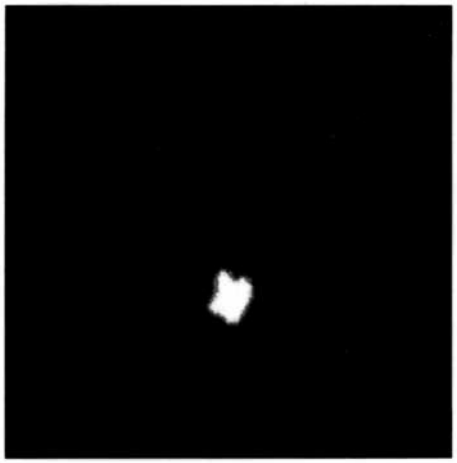
ELECTROMAGNETIC STI RAL HE/

MEASUREMENT METHOD (iii) Local Measurement by Reflection

ELECTRIC IMAGES

9.5 cm X 9.5 cm Samples

$4\ (32)\ [45_2, 0_2, -45_2, 90_2]_{2s}$

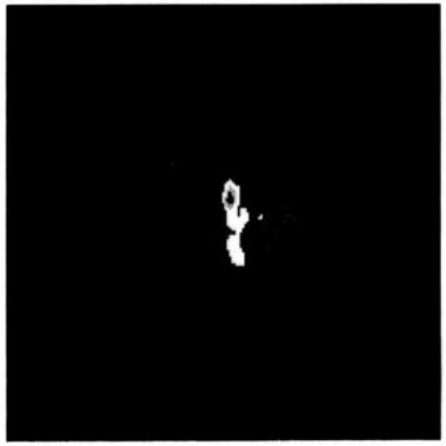


Light Delamination

$2\ (16)\ [45_2, 0_2, -45_2, 90_2]_{s}$

Hard Delamination
(Fibers break)

$4\ (32)\ [45_2, 0_2, -45_2, 90_2]_{2s}$

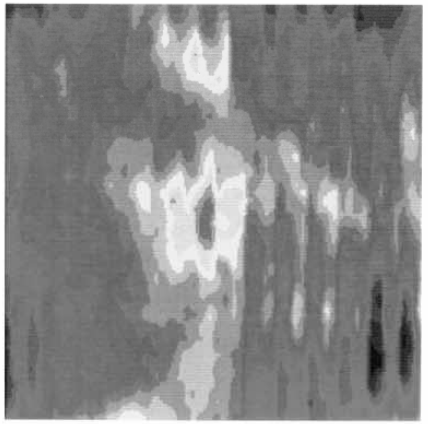


Local Burning

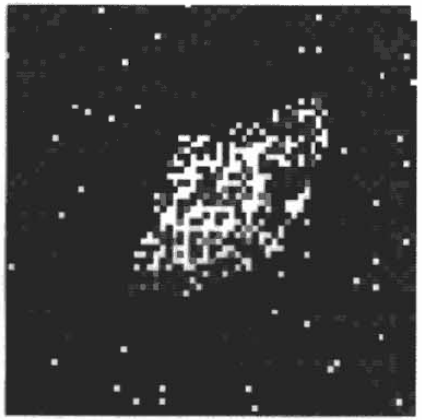
Health Monitoring using electromagnetic fields

MEASUREMENT METHOD (iv) Local Measurement by Reflection

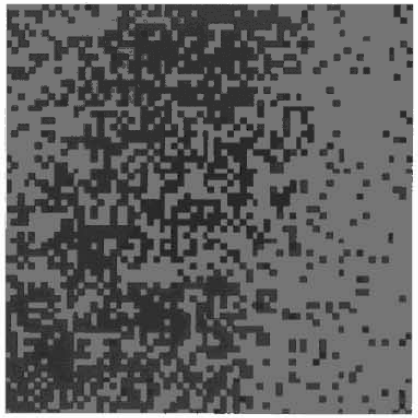
COMPARISON WITH ULTRASONIC IMAGES LOCAL BURNING



Electric Image



C-Scan Ultrasonic Image



D-Scan Ultrasonic Image

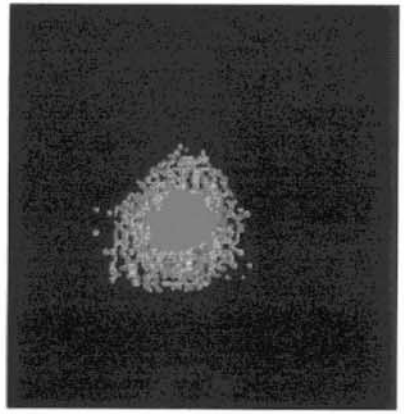
Health Monitoring using electromagnetic fields

ELECTROMAGNETIC STRUCTURAL HEALTH MONITORING

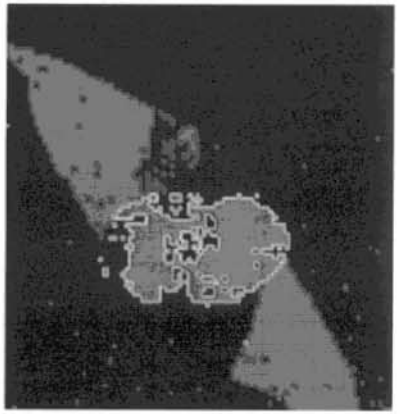
APPLICATION TO HEALTH MONITORING (ii) Active Method

$[45_2, 0_2, -45_2, 90_2]_s$

Delamination

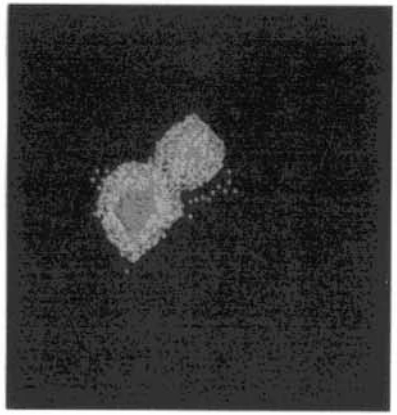


Electric image

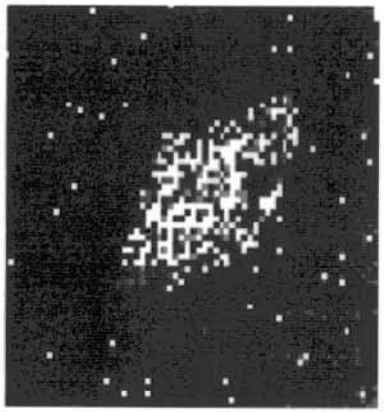


D-Scan US Image

Local burning



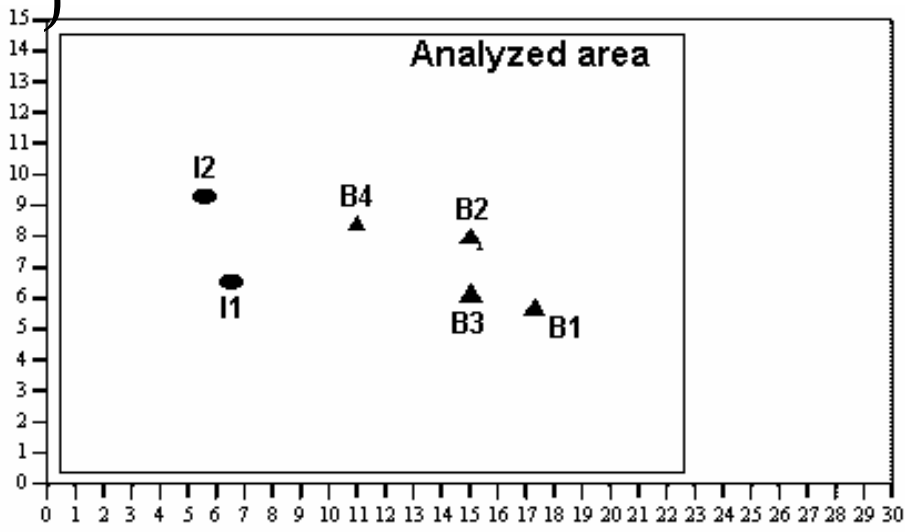
Electric image

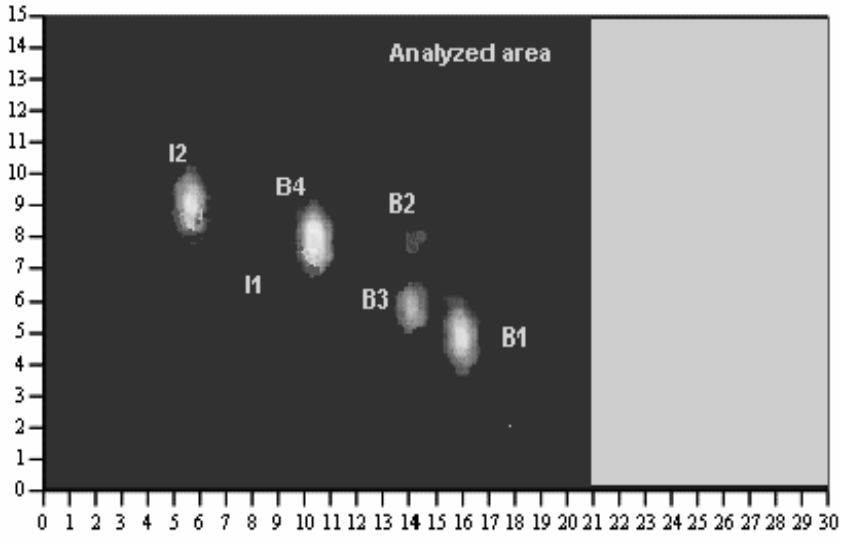


C-Scan US Image

HELP-Layer® SYSTEM: Results

Integrated network system (Patent N° 040 003310 - 31/03/04)

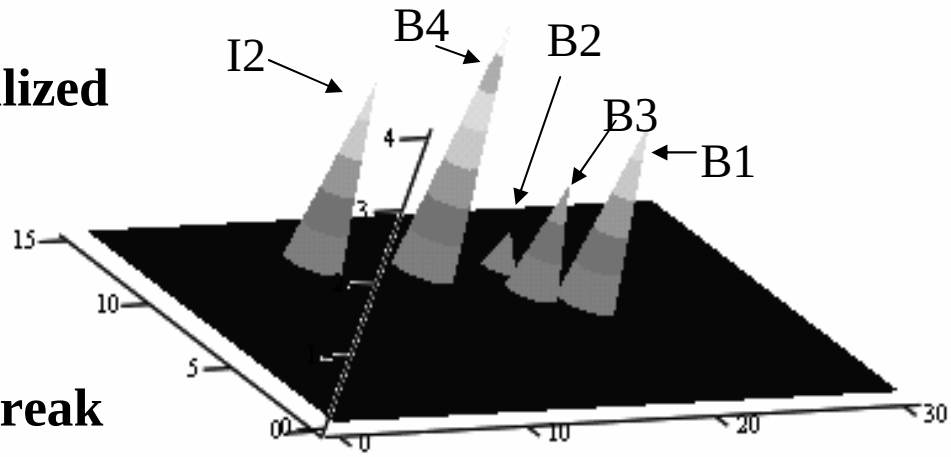




B1, B2, B3, B4, I2: Detected and localized

I1: No detected

Bn : burns, In : impacts
I1 : light impact (2 J) without fiber break



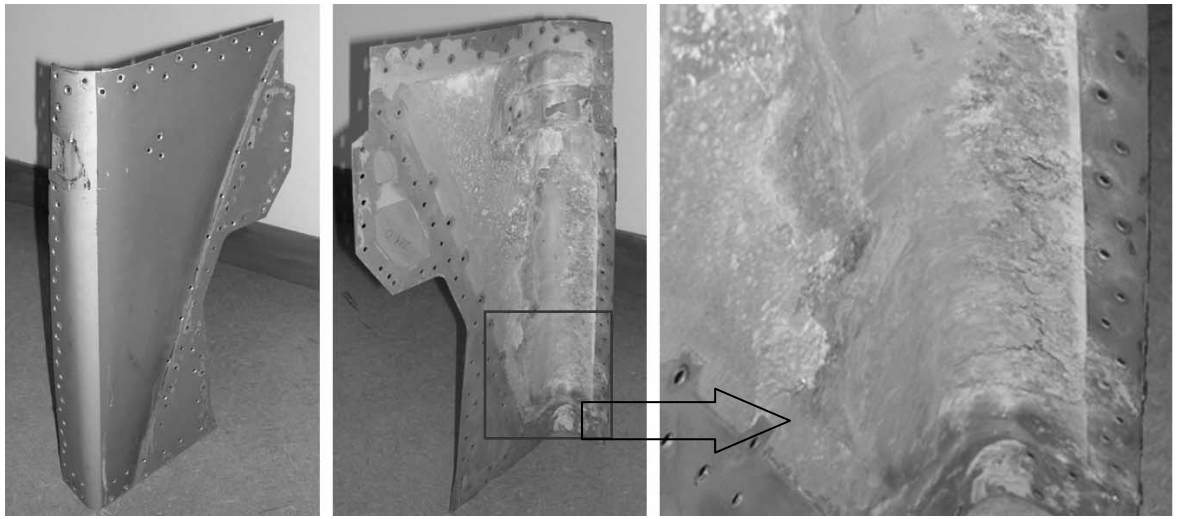
Health Monitoring for corroded structures

Aging of civil and military airplanes

⇒ increasing demand for nondestructive evaluation techniques

corrosion not visible from the outside of the structure

corrosion initiates on the inside or at the interface of aircraft's skins



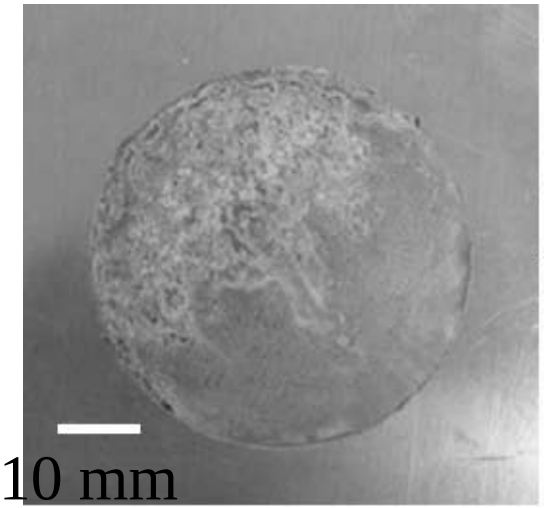
front

back surface of an aircraft component

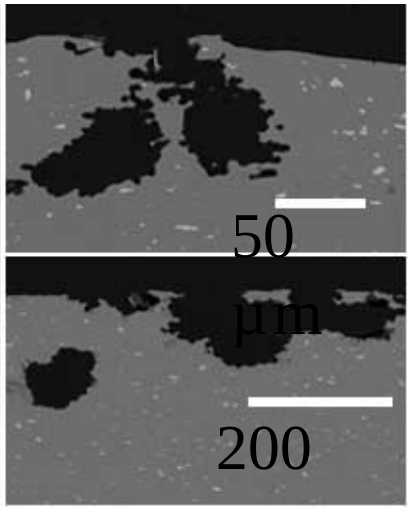
<u>Objective</u> : to detect hidden corrosion without dismounting aircraft's structures

Health Monitoring for corroded structures

Aluminum corroded sample



Corroded zone
(circular area attacked by
salt spray during 192 h)



Microscopic transverse sections
of a corroded sample
(salt spray during 144 h)

Corroded zones characteristics

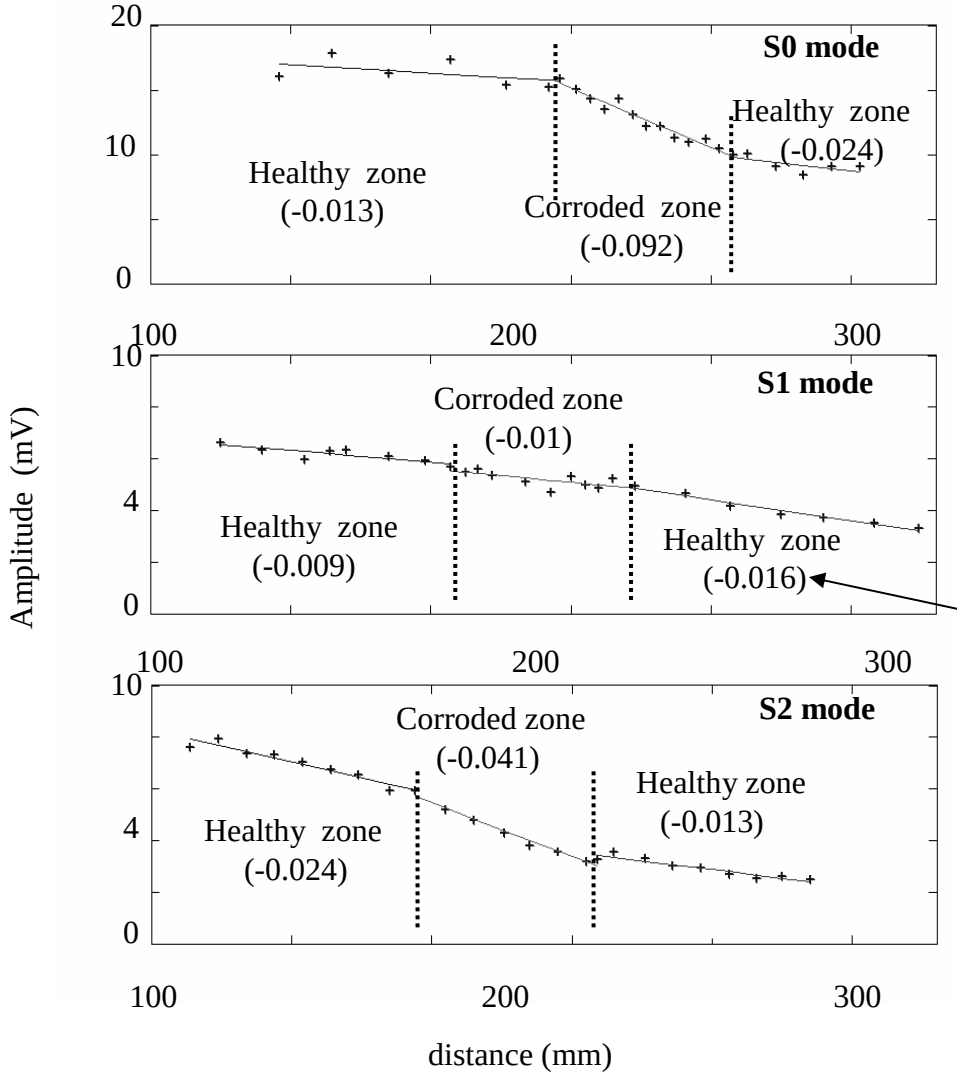
- Aluminum hydroxide
- Rough surface
- Plate thinning
- Pits, cavities

macroscopic scale

microscopic scale

Health Monitoring for corroded structures

Use of Lamb Waves (PhD Thesis N. Terrien)



Lamb mode	$\frac{\text{slope in a corroded zone}}{\text{slope in a healthy zone}}$
S0	4.97
S1	0.8
S2	2.22

Slope of the best-fitting line

S_0 mode seems to be a good choice to detect corrosion

ONERA

Conclusions

ONERA has experience in the development of health monitoring systems using :

1) PZT devices and Lamb waves
2) Network of wires and electromagnetic methods

for various damages : impact, burning, ingress, corrosion

Conclusions

Propositions for a collaboration

1) health monitoring for sandwich structures

2) health monitoring for corrosion of metallic structures

3) smart patches for metallic or composite structures