

# Inspection de billettes Titane par ultrasons avancés

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**09/09/2025**



# AGENDA

**01** Qui sommes-nous ?

**02** Problématique

**03** Approche par techniques avancées

**04** Résultats et conclusion

# 01

## Qui sommes-nous ?

- Entreprise française à envergure internationale
- Basée à Nantes
- Expert en ultrasons
- Concepteur et fabricant d'électronique US et de logiciels

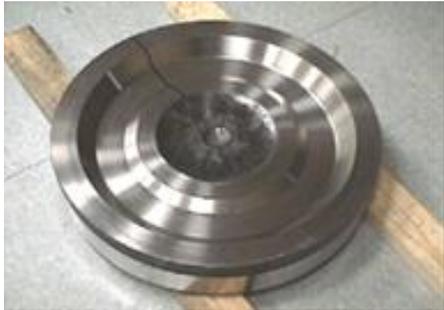
# Vidéo de présentation

## TPAC | Unique in NDT (French) - YouTube



# 02 Problématique

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Billetes dans l'aéronautique et dans le spatial

En titane et alliages Nickel

Utilisées pour fabriquer les pièces tournantes des moteurs

Aujourd'hui, CND UT conventionnel principalement utilisé, basé sur l'amplitude et l'équivalence amplitude / défaut

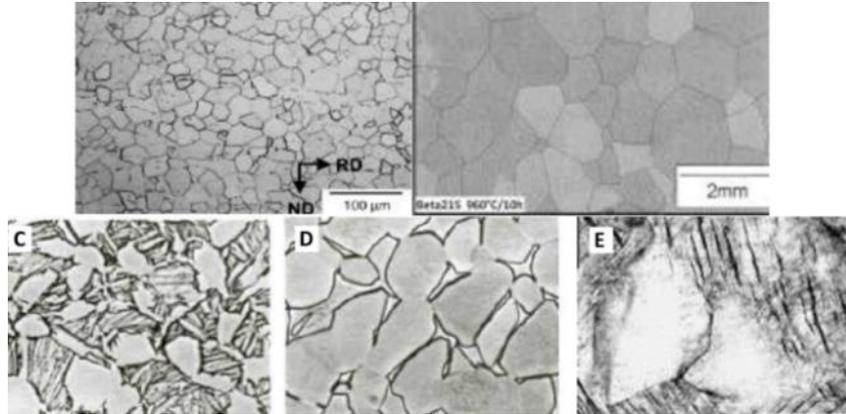
- **Types de défauts :**

- Porosité
- Inclusion

- **Limitations :**

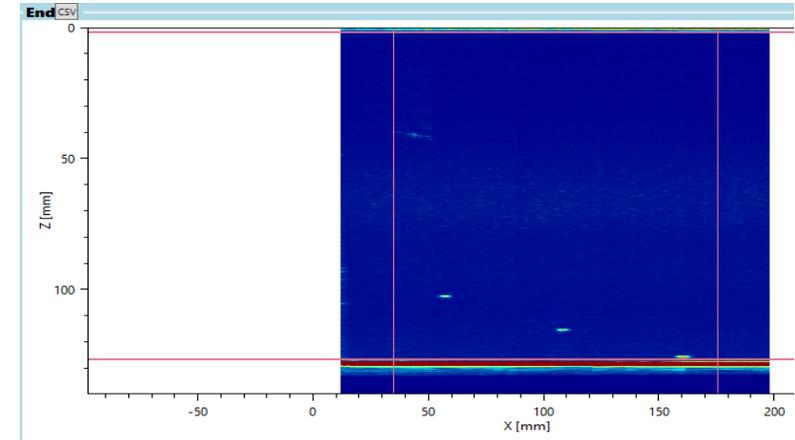
- Influence du fibrage de la pièce
- Influence type, forme et orientation sur l'amplitude de détection
- SNR – bruit de structure

## Points de vigilance



- Microstructure du titane : Matériau « bruyant » du fait de la taille et de la structure des grains
- Courbure de la barre / colonne d'eau
- Le pas de contrôle

## Objectifs



- Améliorer le Rapport sur Bruit (SNR)
- Améliorer la détectabilité
- Diminuer le temps de contrôle

# 03 Approche par techniques avancées

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FMC : Full Matrix Capture

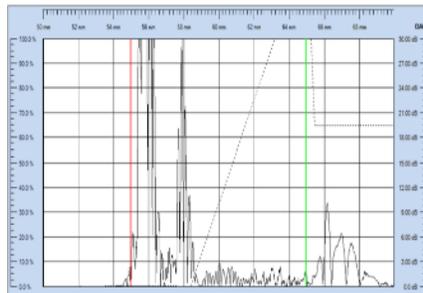
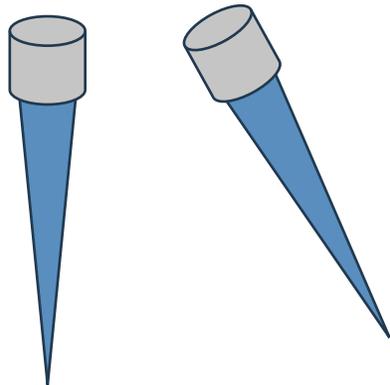
PWI : Plane Wave Imaging

TFM : Total focusing method

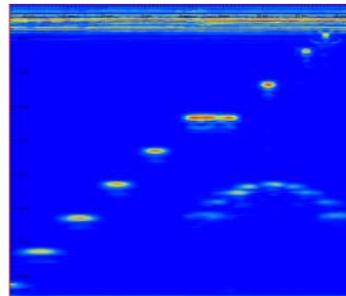
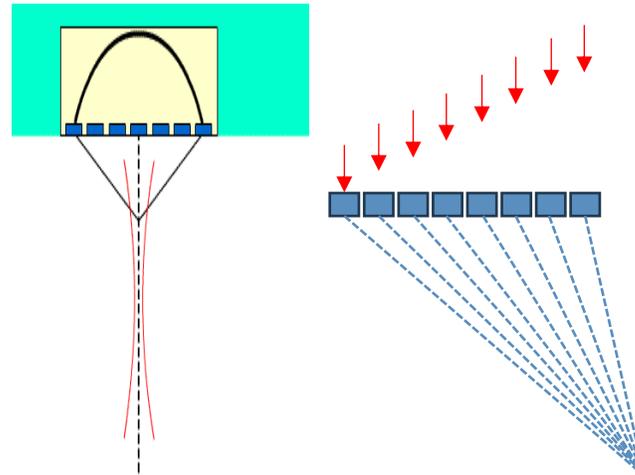
Adaptatif : ATFM, APWI

## Conventionnel

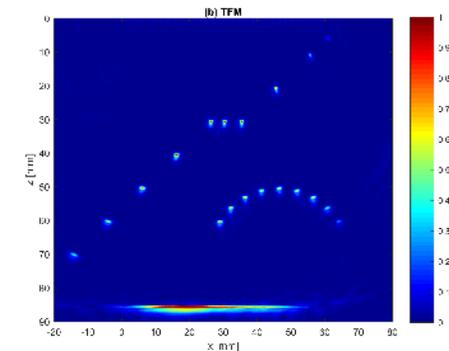
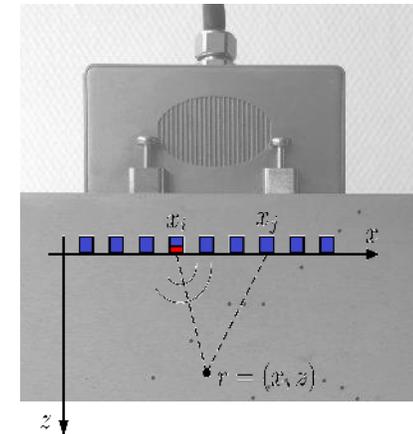
Pilotage et mise au point mécanique

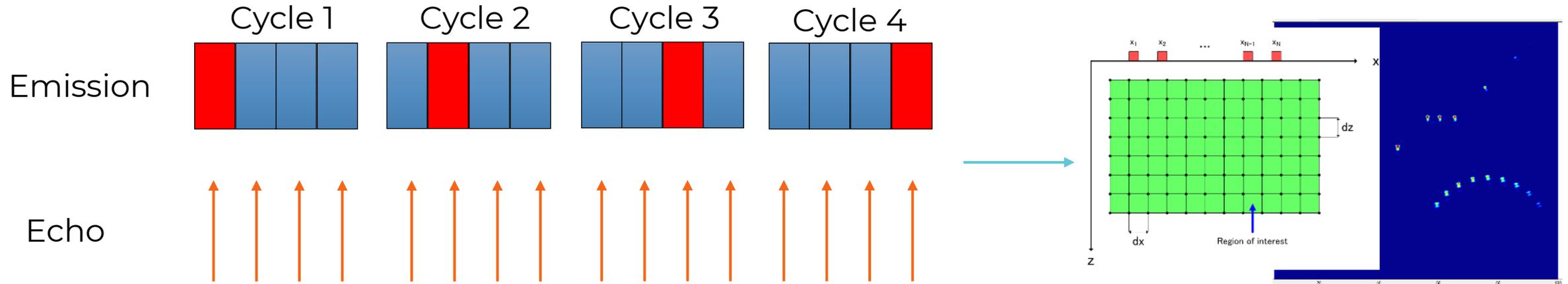


## Phased Array



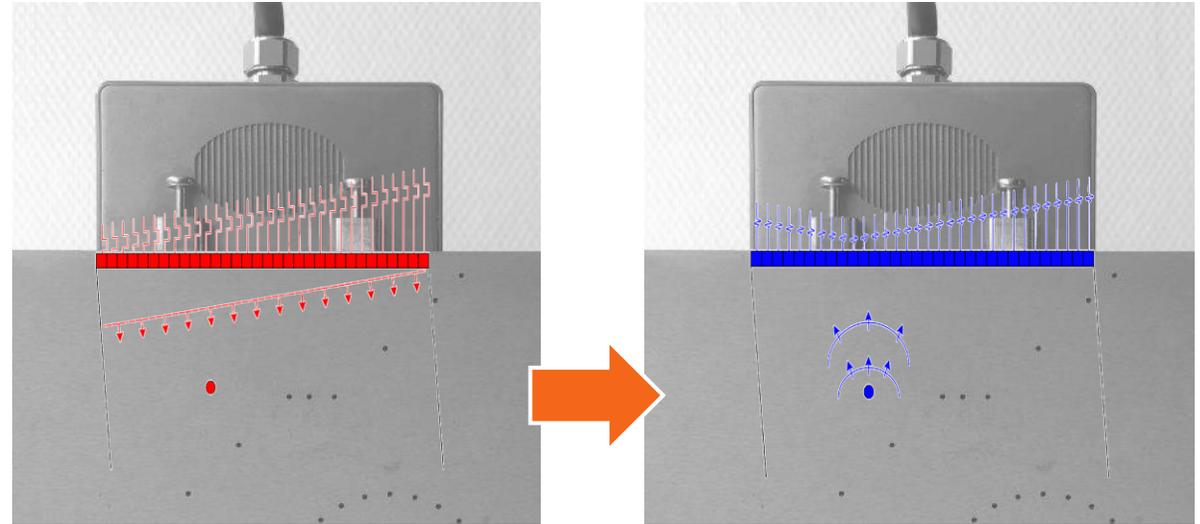
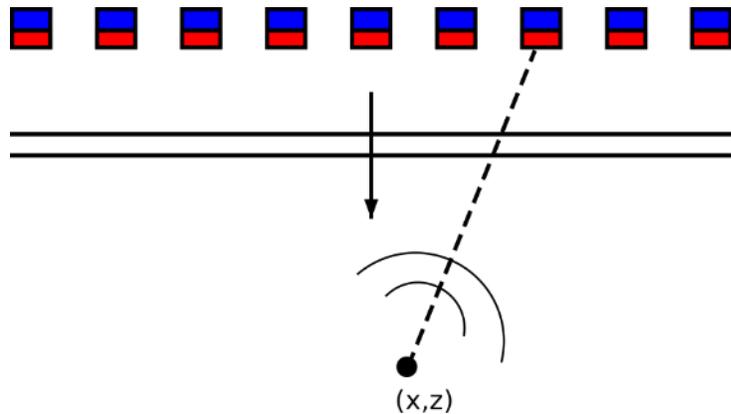
## Avancés FMC/TFM, PWI...





- **FMC : Full Matrix Capture**  
Schéma d'acquisition de données « brutes » réalisé directement par l'instrument
- **TFM : Total Focusing Method**  
Reconstruction d'image en temps réel à partir des données FMC
- **Bénéfices :**
  - Résolution d'image bien meilleure
  - Détectabilité : petite taille ou faiblement « réfléchissant »
  - Imagerie fidèle permettant une interprétation plus facile et moins de faux positifs
  - Données FMC permettant des post-traitements différents

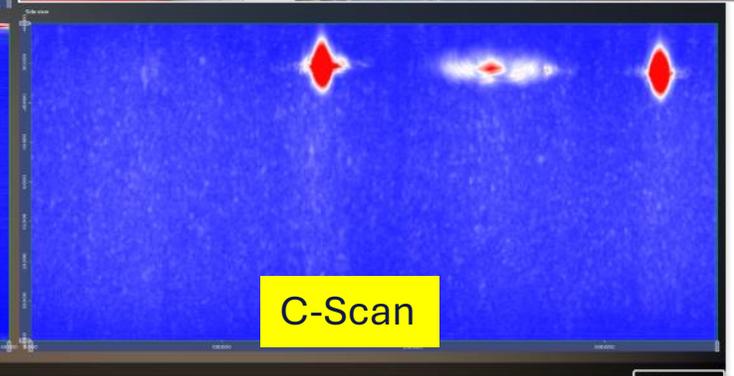
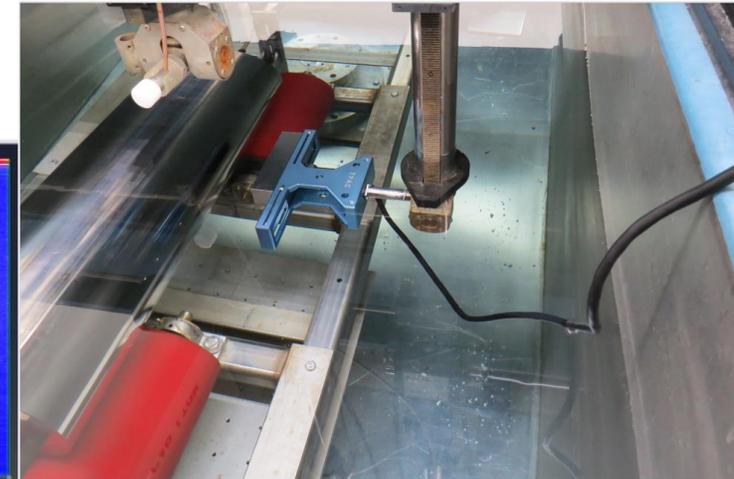
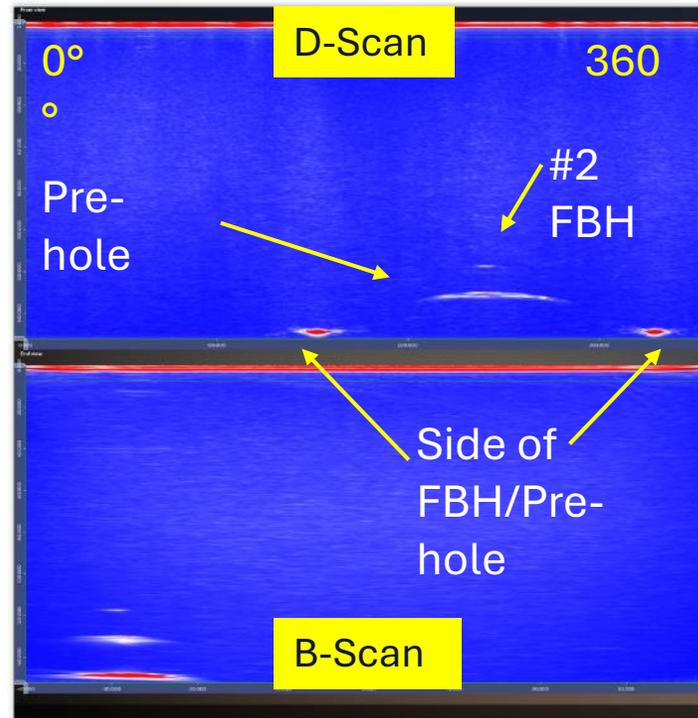
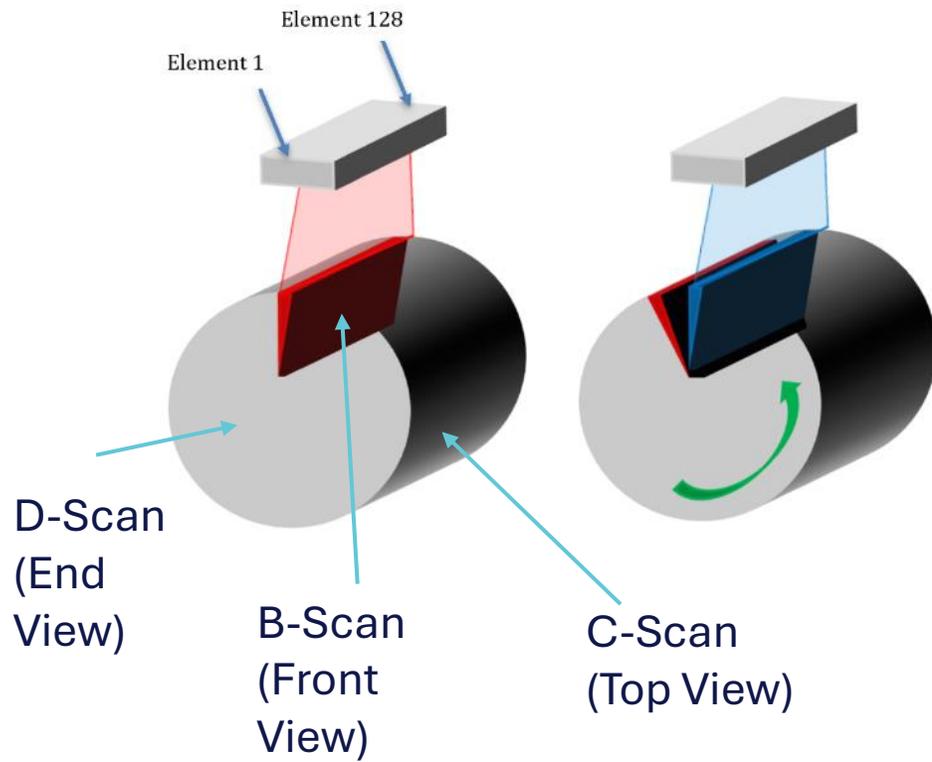
PWI



## • Bénéfices :

- Vitesse d'acquisition très rapide
- Résolution d'image meilleure
- Meilleure clarté des défauts grâce aux reconstructions des signaux
- Moins de données qu'en FMC
- Flexibilité dans l'analyse en post-traitement des données PWI

# Approche | Convention de vues



# Approche | Système mécanique



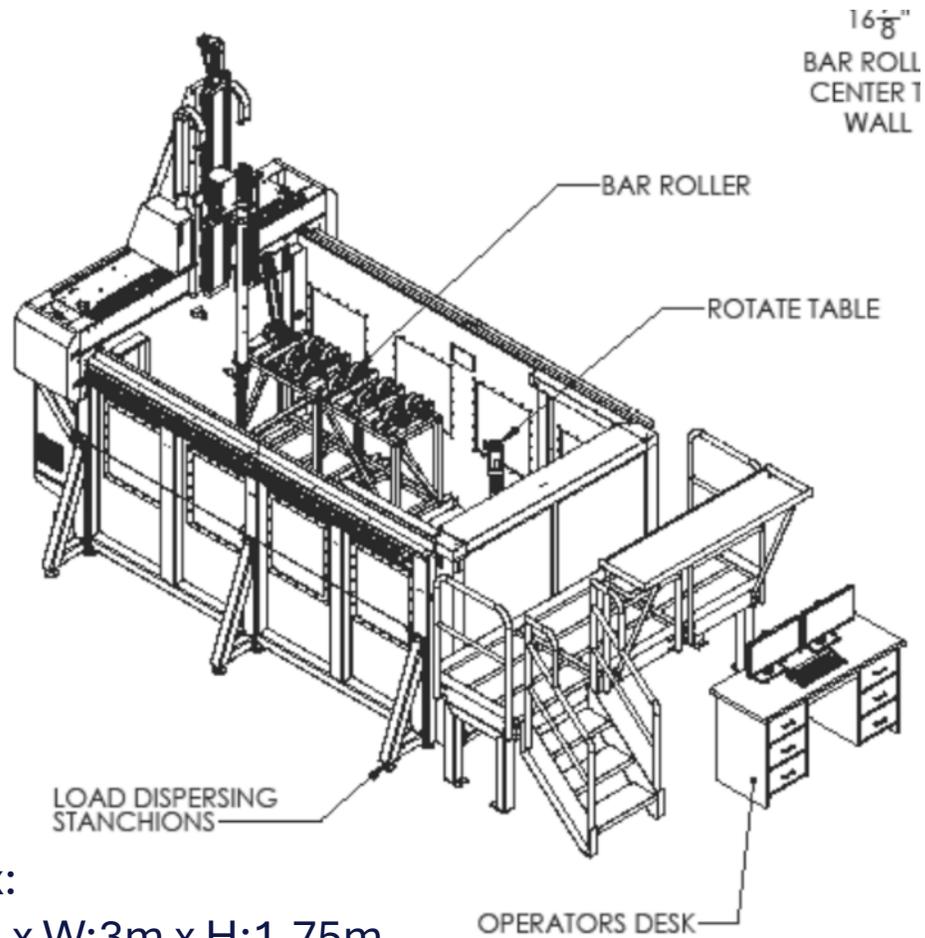
Probe

Billet immersed in water

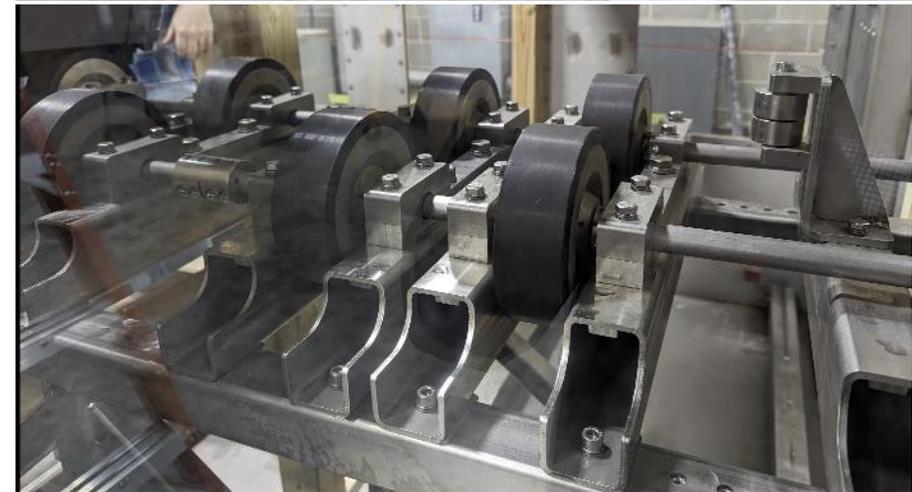
Wheel Encoder



# Approche | Nouveau système mécanique



Approx:  
L:4.5m x W:3m x H:1.75m





Gamme Pilot - Conventiennel

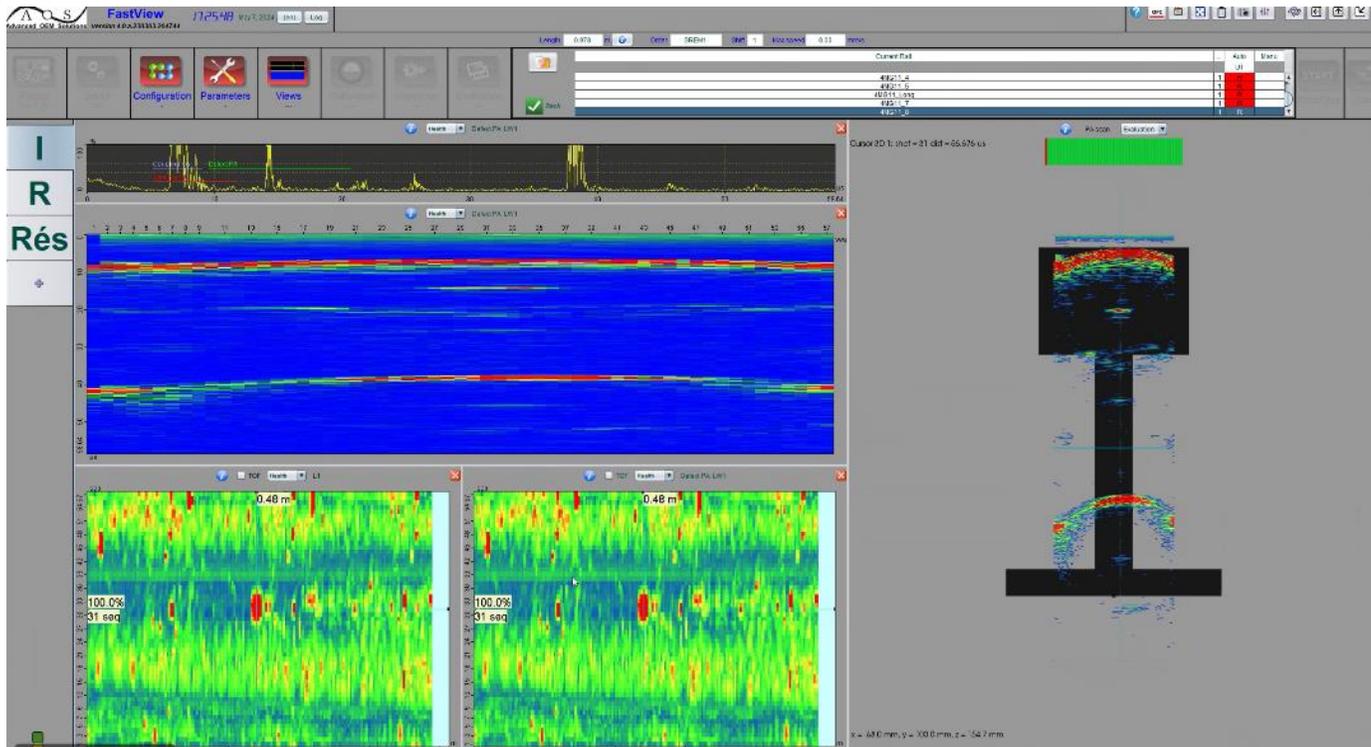


Gamme Explorer – PA et Avancés



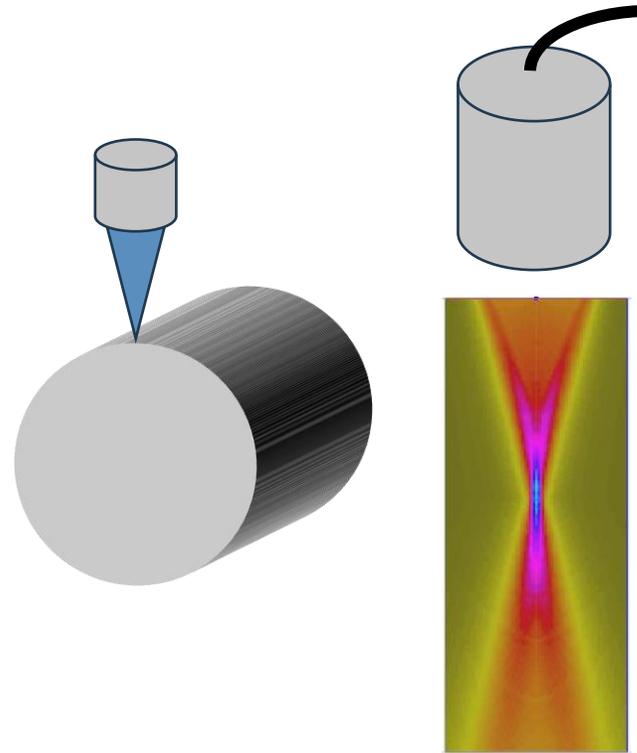
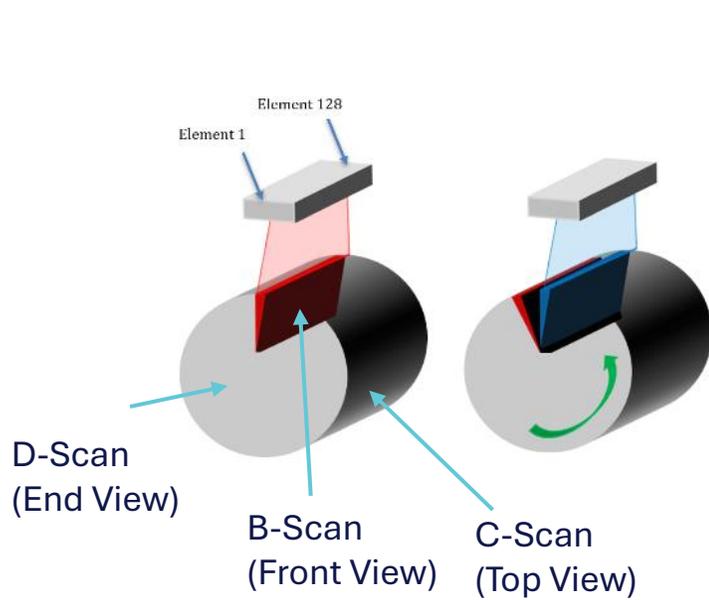
## Pioneer

- Phased Array + Techniques avancés
- Conventiennel multi-canaux
- Centres et laboratoires R&D et universitaires
- **Facilité d'utilisation des technologies avancées**
- **Débit de données et calcul sur GPU**
- **Accès aux données brutes**

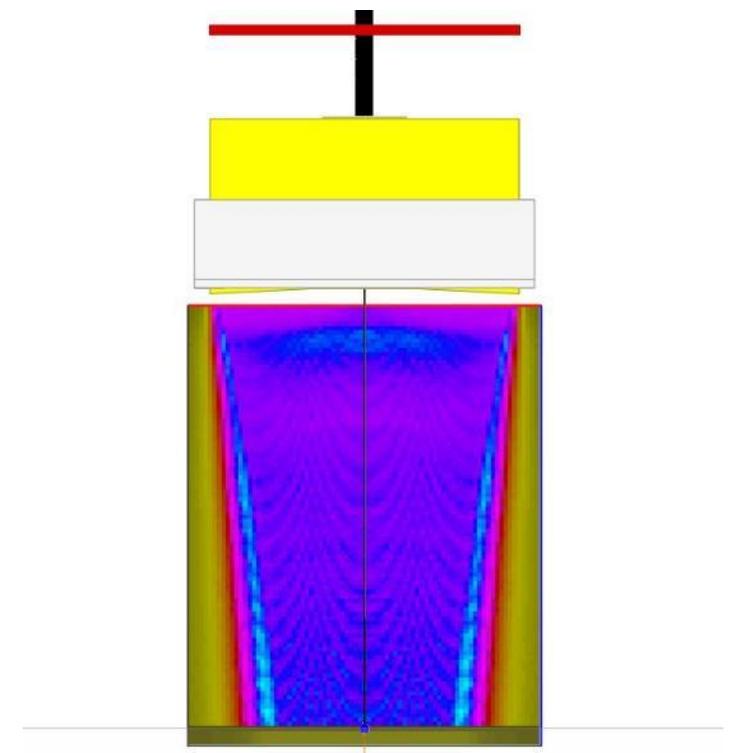


- Logiciel multi-usages et multi-sectoriels
- Conception avec une grande couverture de cas de contrôle
- Paramétrable pour une utilisation simple et efficace en fabrication
- Flexible dans son interface et qui peut recevoir nombre de sondes et d'instruments

# Approche | Sonde et productivité



UT conventionnel : taille faisceau



Sonde linéaire permettant une plus grande zone d'inspection

👍 **Pas hélicoïdal plus grand => meilleure productivité**

# Approche | Productivité

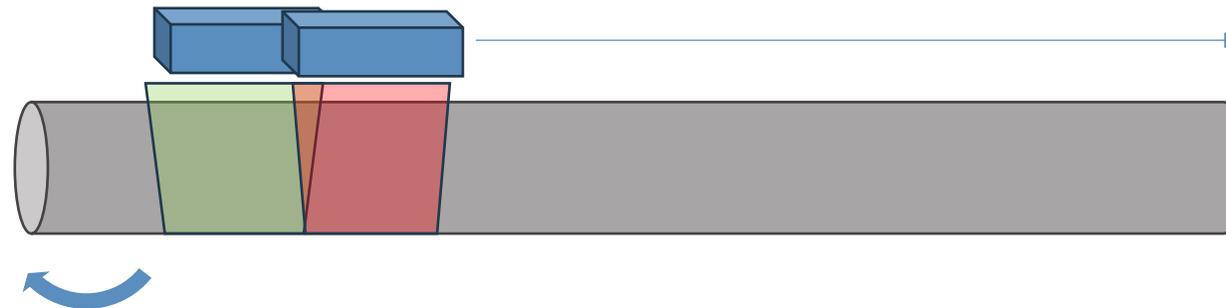
## Exemple:

- Adaptive Plane Wave Imaging (APWI)
- Largeur sonde linéaire : 127mm
- Longueur barre : 6m (20')
- Diamètre DN300 (12")
- Rotation 360° avec un pas de 1mm
- Temps d'une rotation : 30s (plutôt lent)
- Hypothèse d'un recouvrement de 80%, ce qui est très conservateur

=> **Temps d'inspection : 30 min**

- **$(6\text{m} / 101,6\text{mm}) \times 30\text{ s} = 30\text{ min}$**
- En conventionnel : peut aller jusqu'à 1 jour d'inspection

👍 Amélioration de la productivité



# 04 Résultats et conclusion

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19 Blocs de calibration Ti6AL4V  
Trous à fond plat



PACS - Trous à fond plat

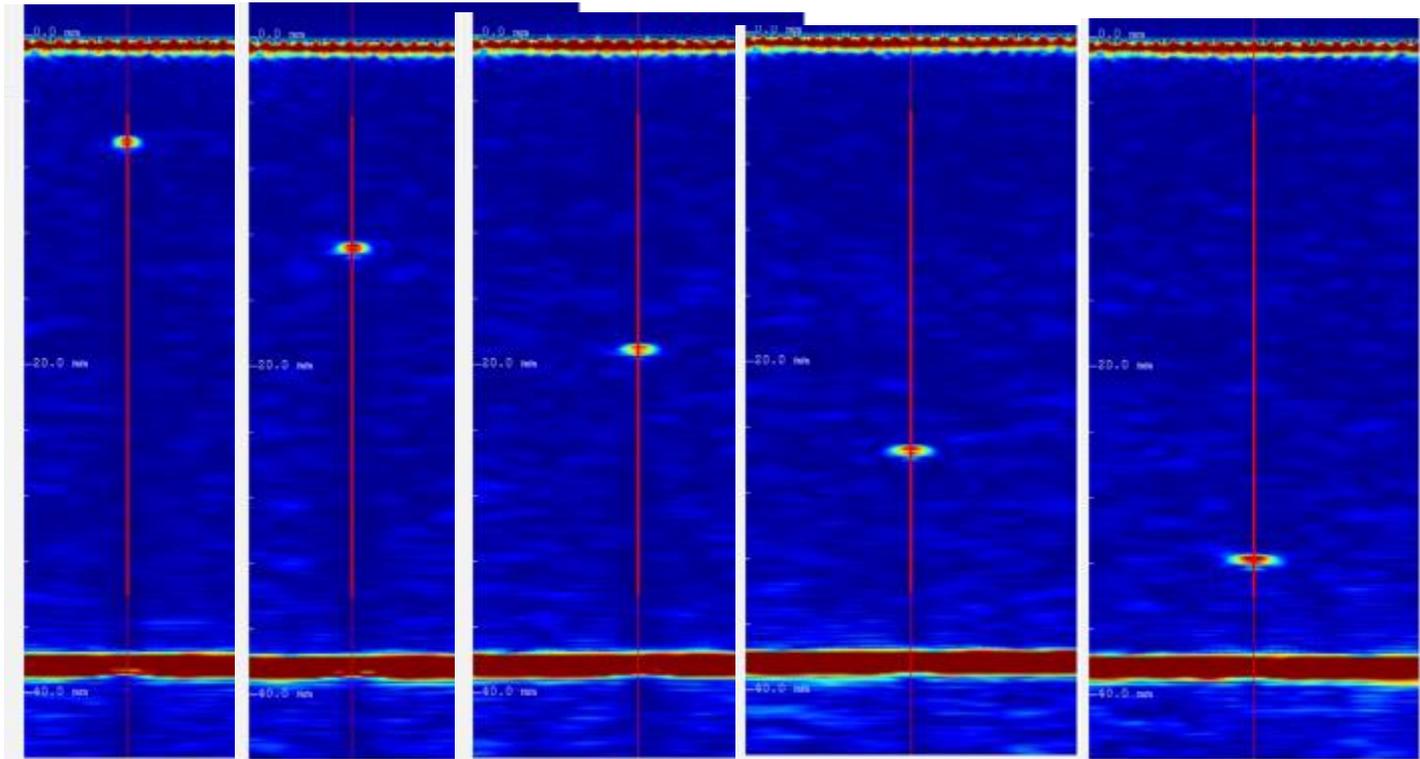
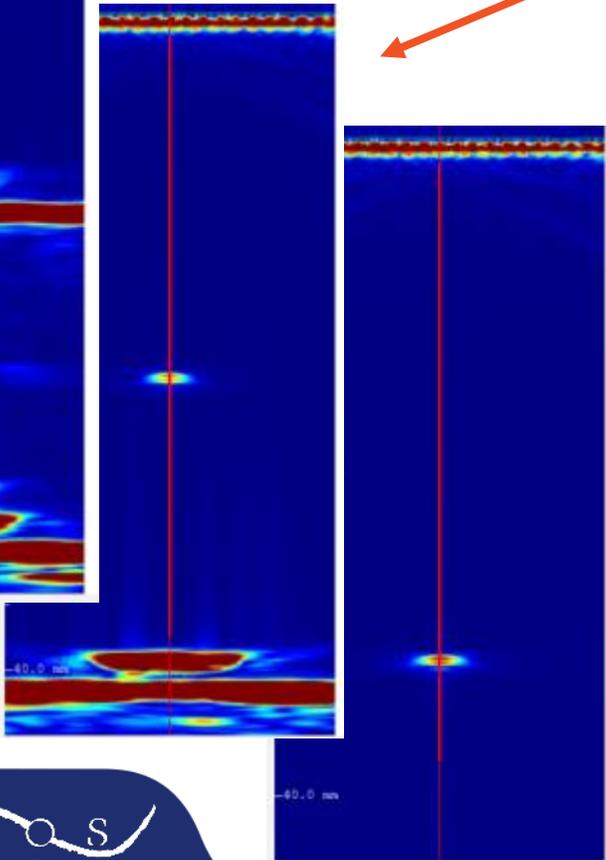
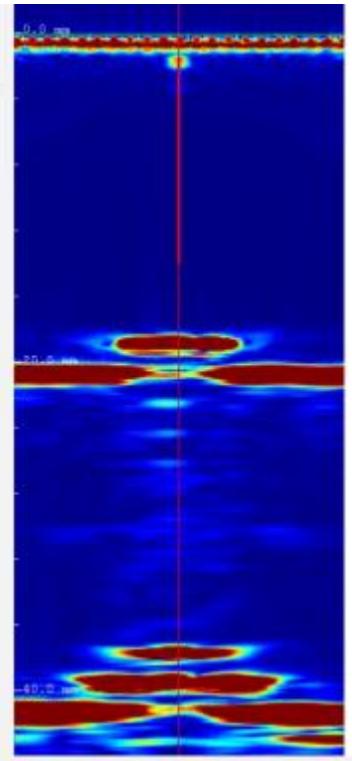
PACS - Side Drilled holes



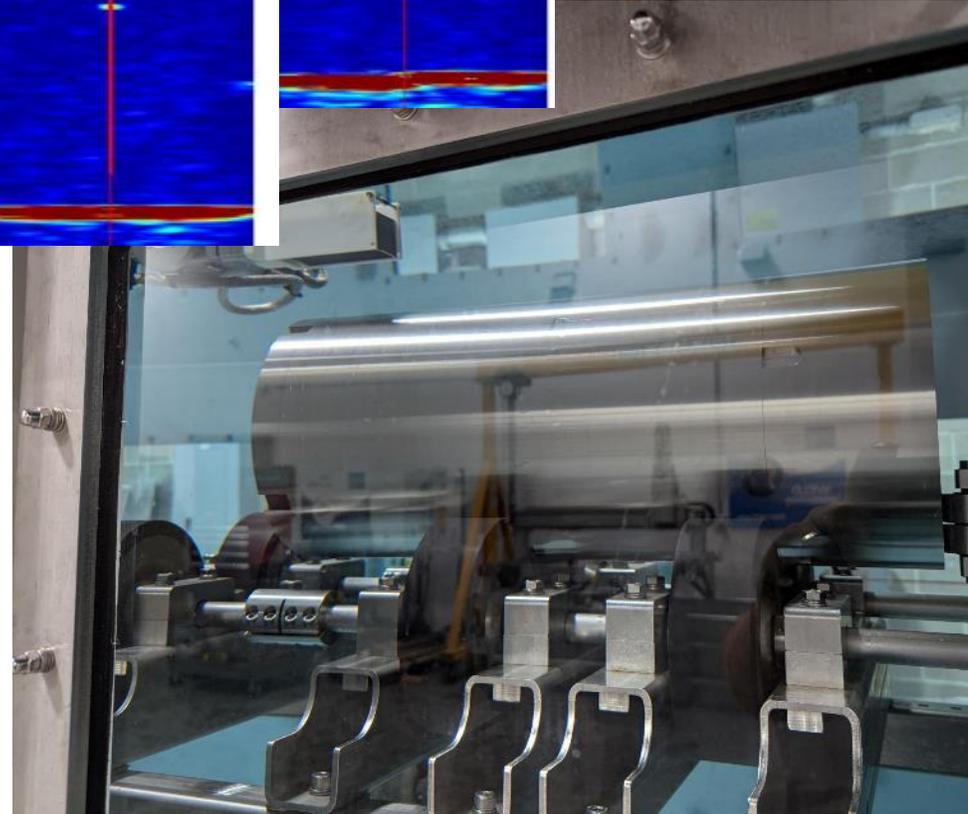
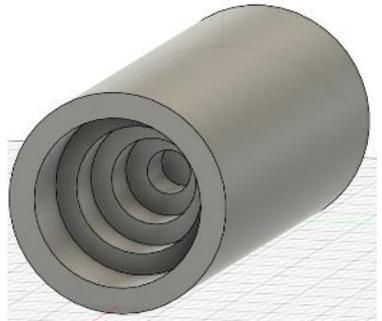
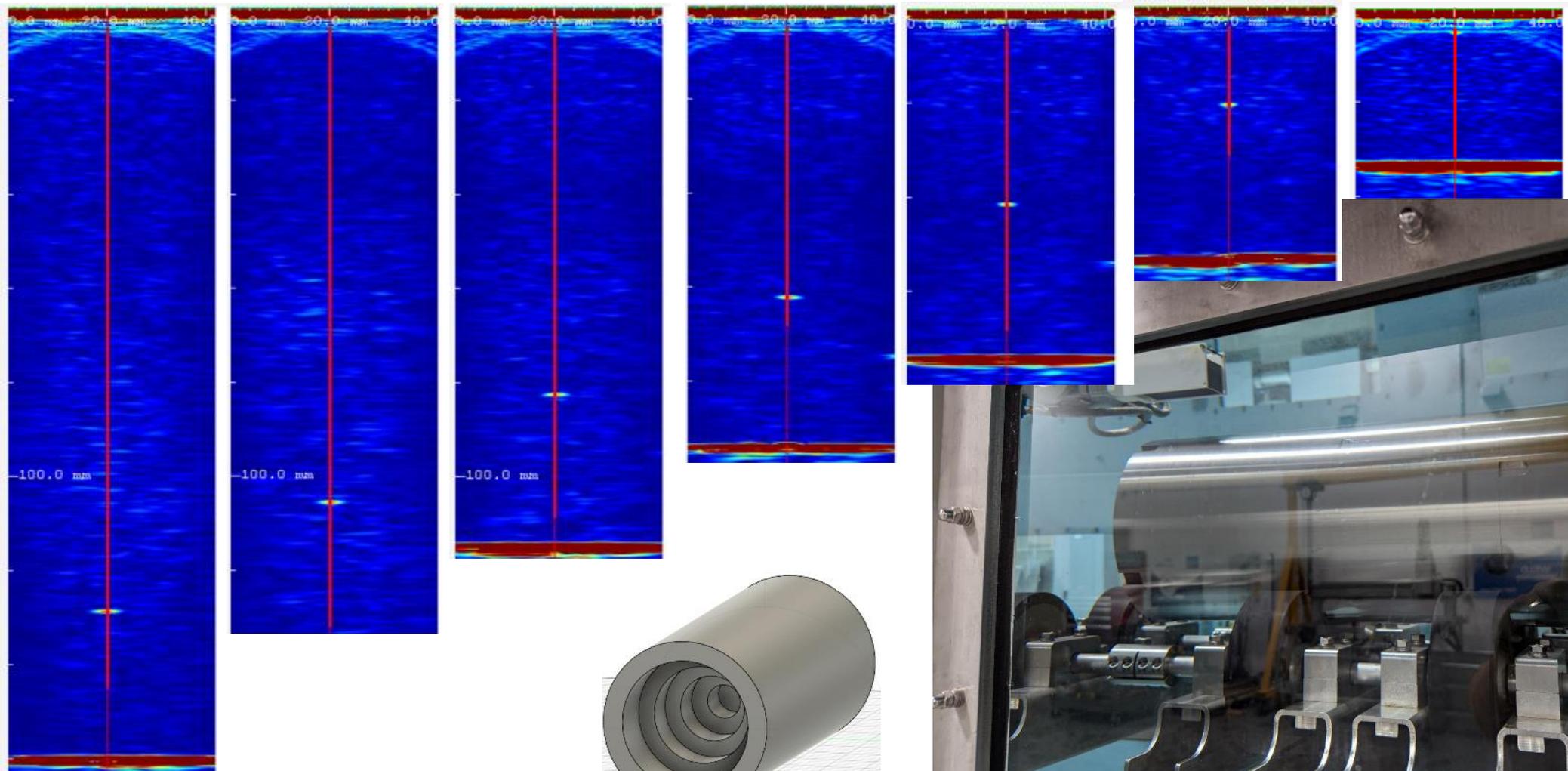
# Résultats | Bruit



Ti6Al4V  
Trous à fond plat



# Résultats | Bruit

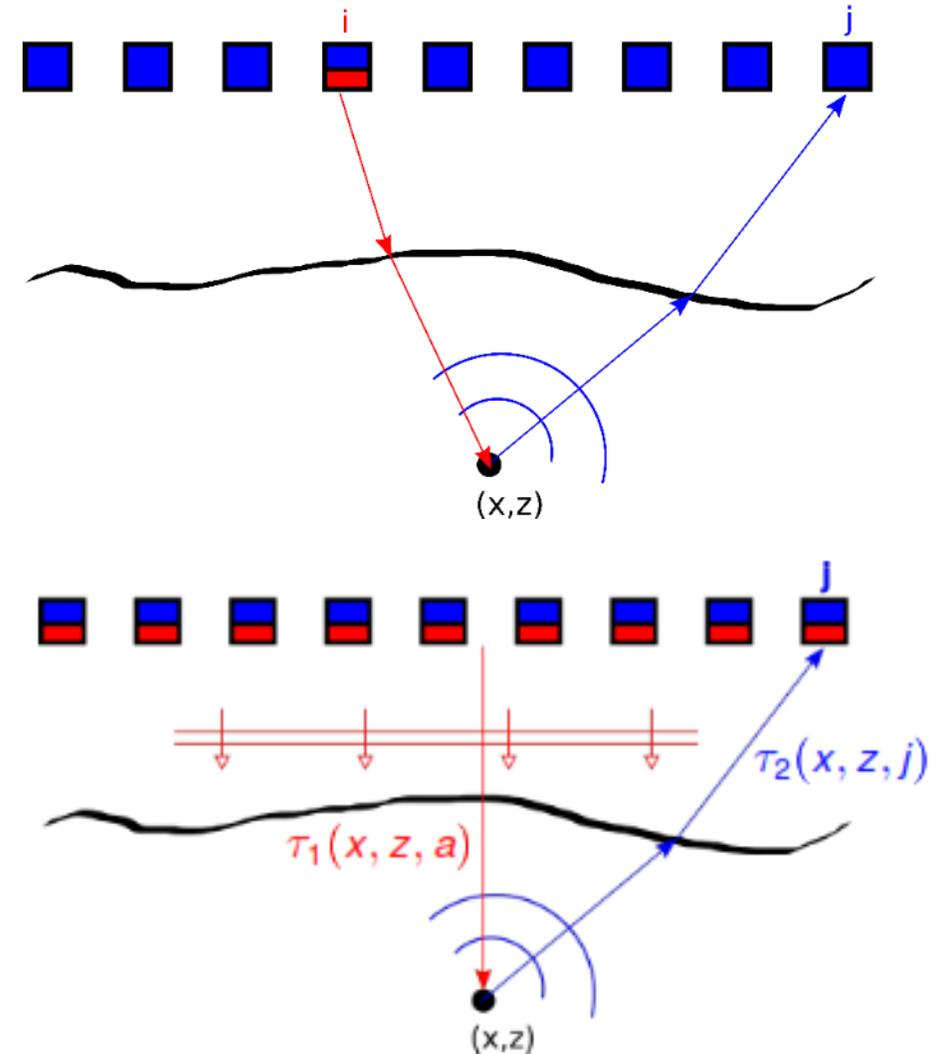


## Adaptatif :

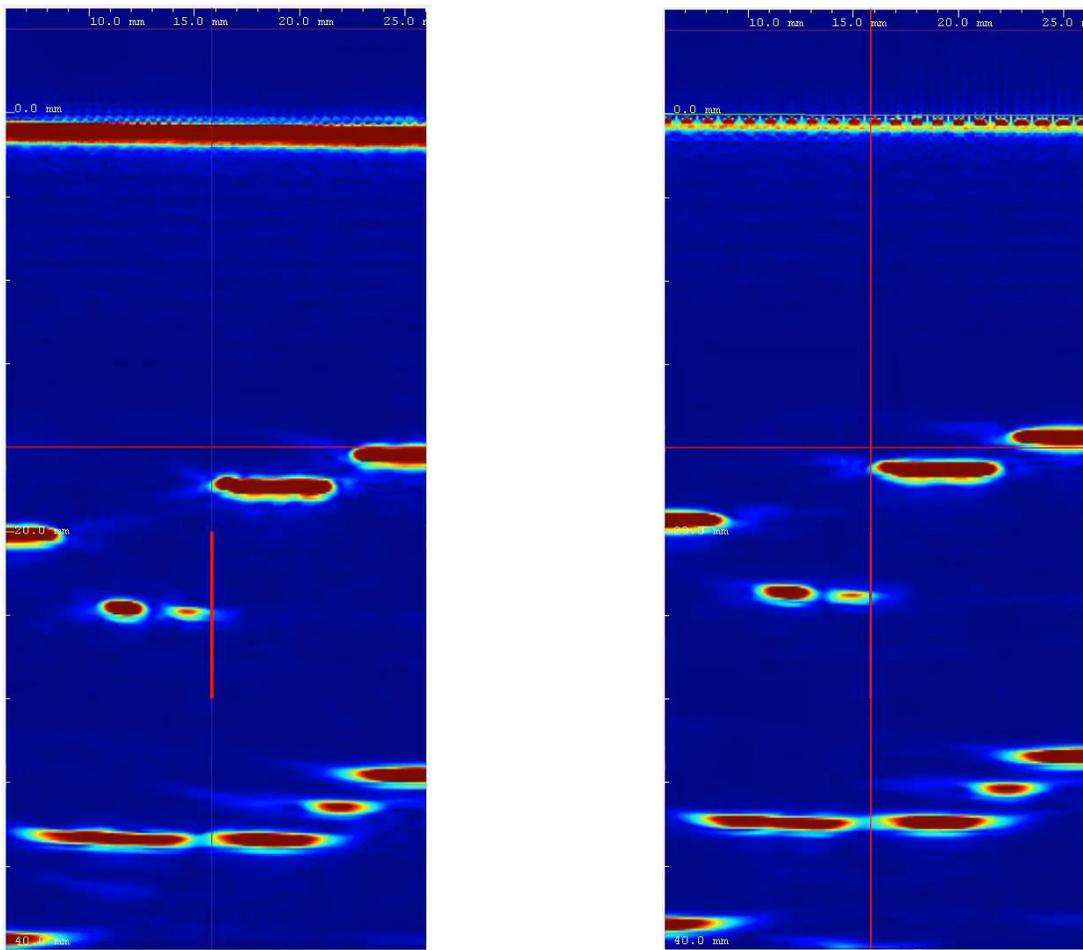
- Mesurer la surface grâce aux échos d'interface reçus par tous les éléments
- Appliquer l'algorithme TFM aux données précédemment réceptionnées pour prendre en compte la surface... en temps réel!

**En immersion, permet de compenser la variation de la colonne d'eau**

**=> Pertinence de l'adaptatif**



## Moving Probe Up and Down in Immersion



**Précision de la  
profondeur**

**Image claire**

# Conclusion

## Avantages des techniques avancées pour l'inspection des billettes

- Amélioration du rapport signal/bruit (SNR)
- Amélioration de la détectabilité
- Vitesse d'inspection plus rapide
- Assure une image fiable et une profondeur précise en immersion

## Suite

- Essais avec la Phase Coherence Imaging (PCI), en proche surface
- Collaboration industrielle



UNIQUE IN NDT



# Inspection en UT Air sur du composite



09/09/2025



# AGENDA

**01** Principes

**02** Moyen d'inspection

**03** Essais

**04** Conclusion

# 01 Principes

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# PRINCIPES : Acoustique

## Acoustic waves in air

Wave modes: Longitudinal wave

Velocity (c): 340 m/s

Acoustic Impedance (Z): 4.0 e-4 Mrayls

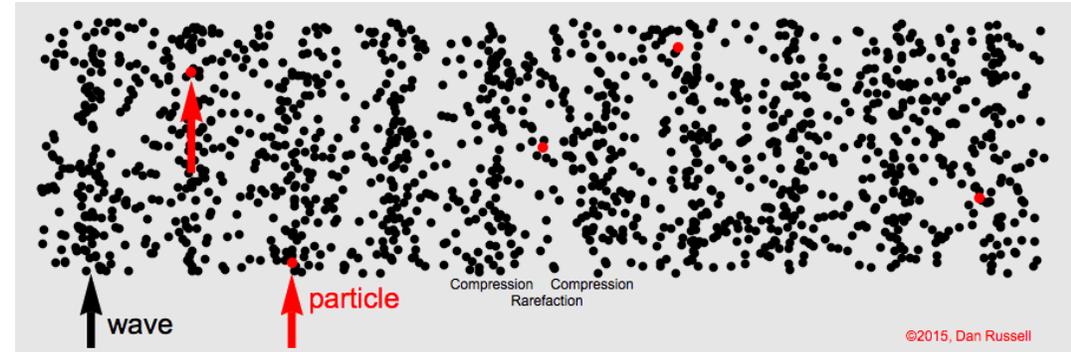
## Acoustic Impedance (Z)

$$Z = \rho c$$

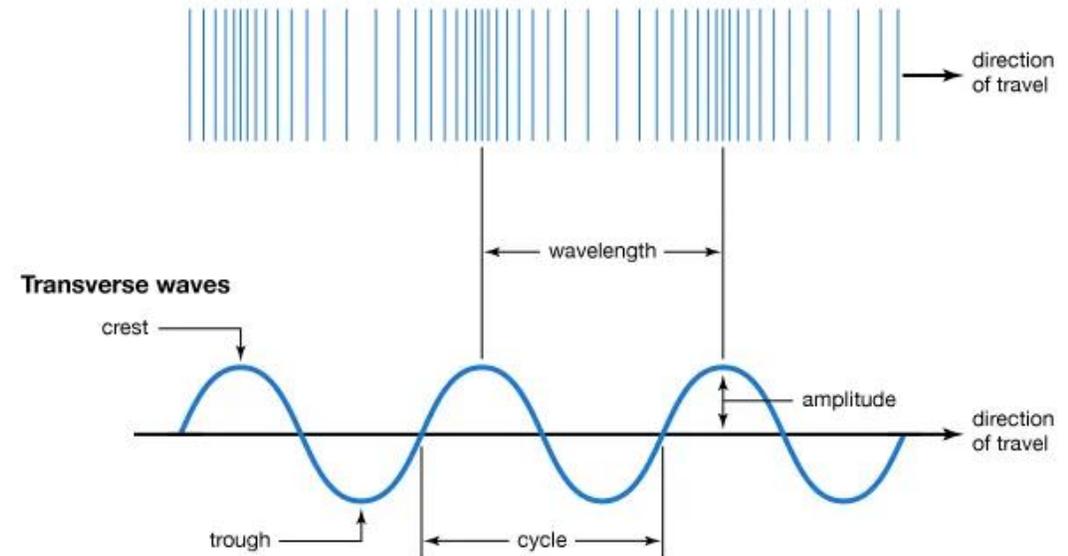
$$Z = \frac{P}{v}$$

$\rho$  : materials density

P: acoutic pressure



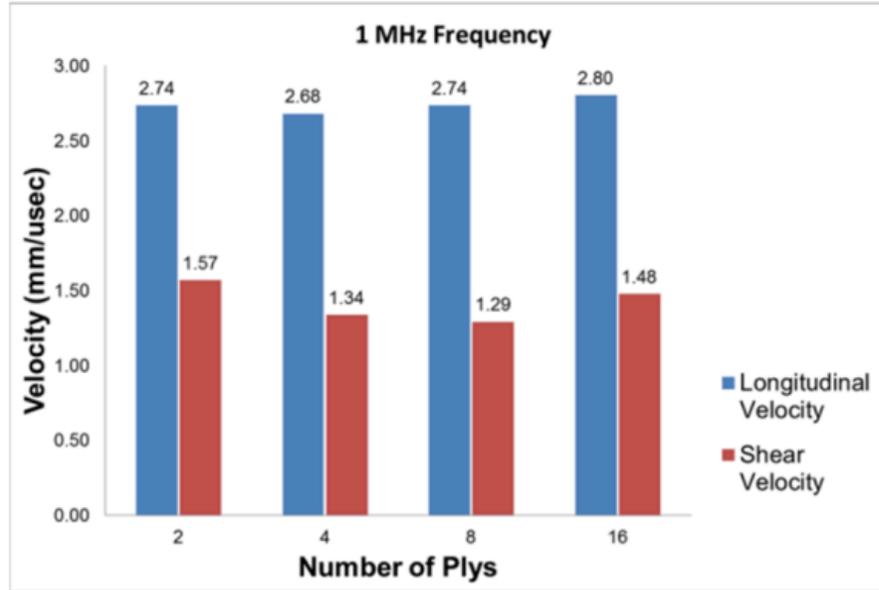
Longitudinal waves



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# PRINCIPES

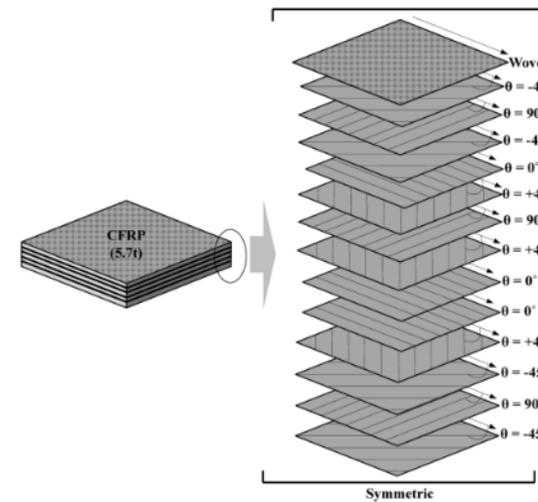
## CFRP:



A. M. Dorado and D. G. Moore, Composite Material Characterization using Acoustic Wave Speed Measurements, SAND2015-8037C.

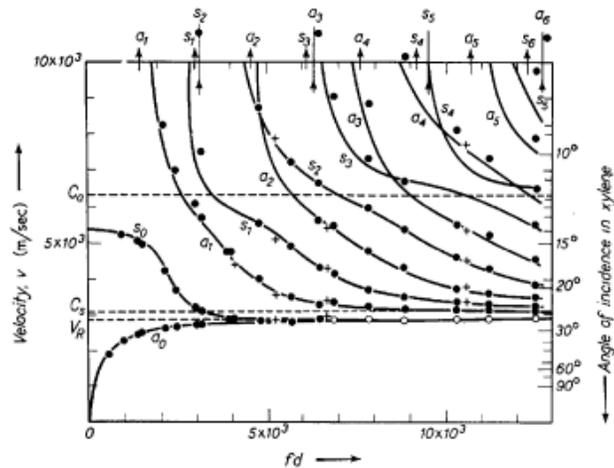
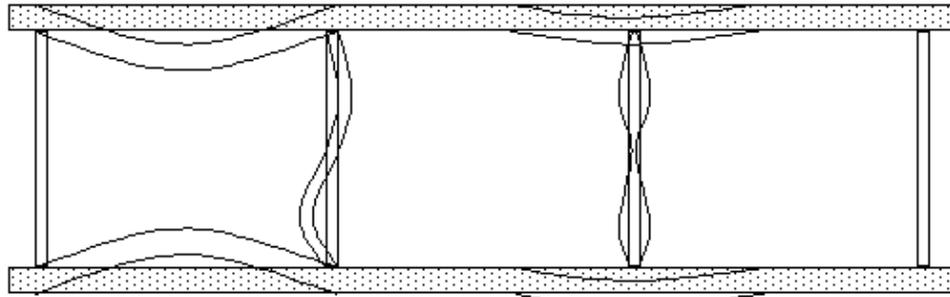
$$V_L \approx 2800 \text{ mm/s}$$

$$V_S \approx 1500 \text{ mm/s}$$

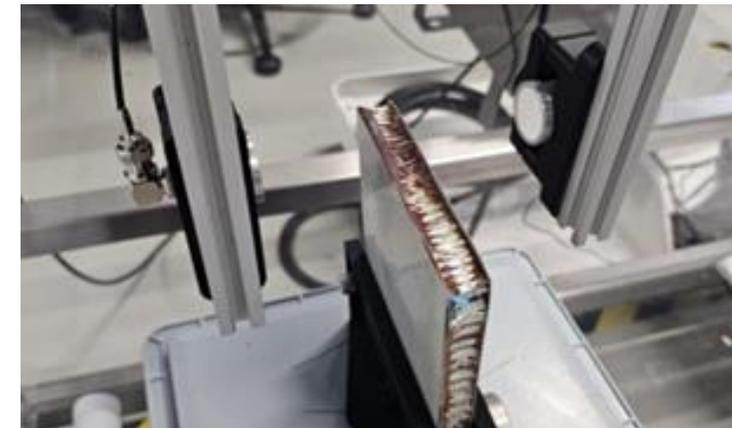
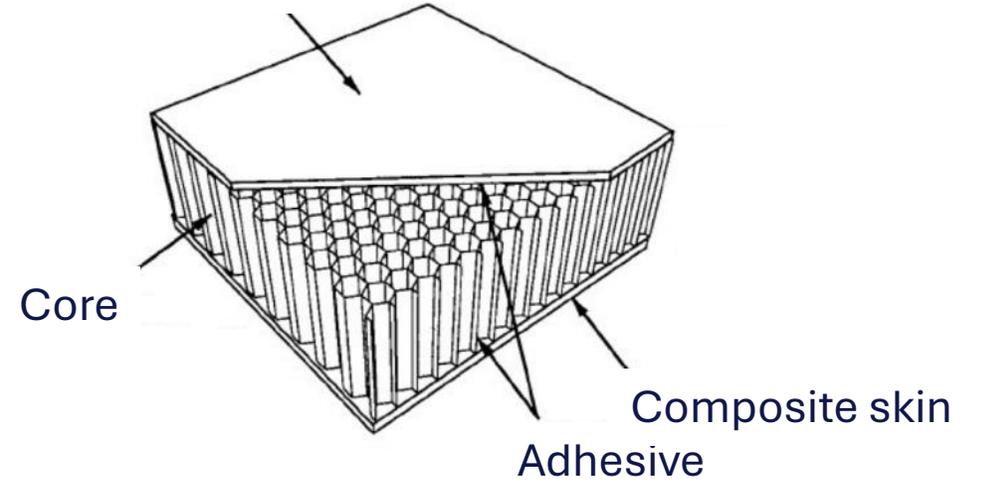


# PRINCIPES

Jan O. Strycek, Willem A. Grandia, and Hanspeter Loertscher, WAVE MODES PRODUCED BY AIR COUPLED ULTRASOUND, <https://www.ndt.net/article/wsho0597/qmi2/qmi2.htm#ref>



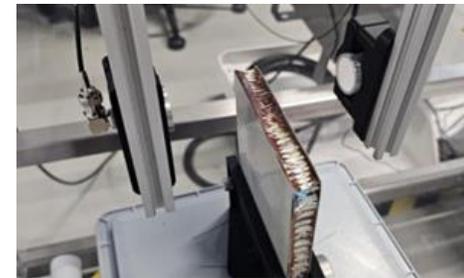
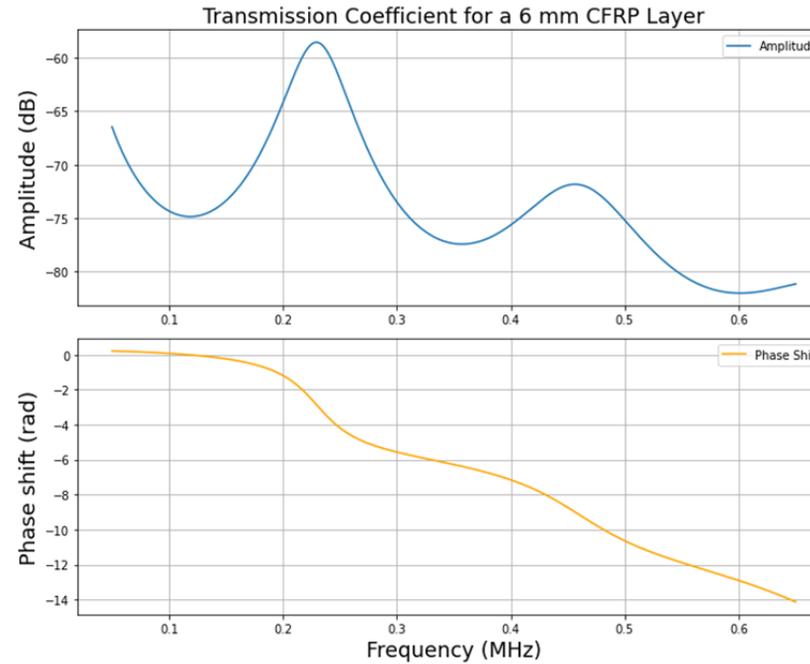
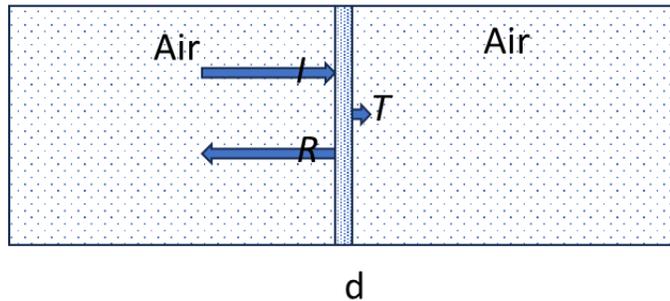
Composite skin



# PRINCIPES : Atténuation et résonance

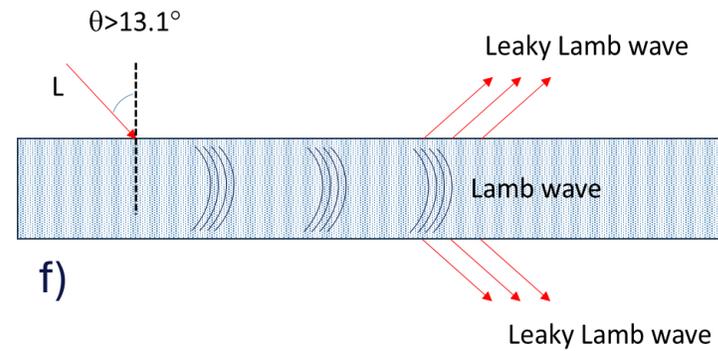
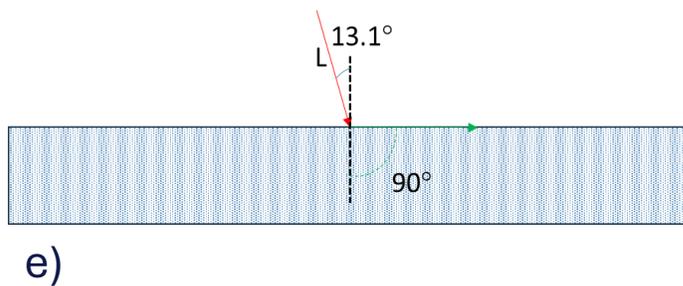
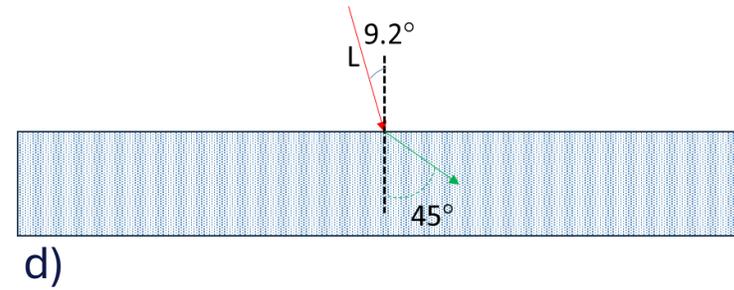
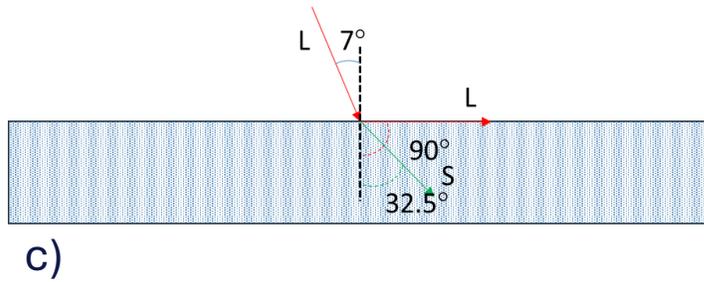
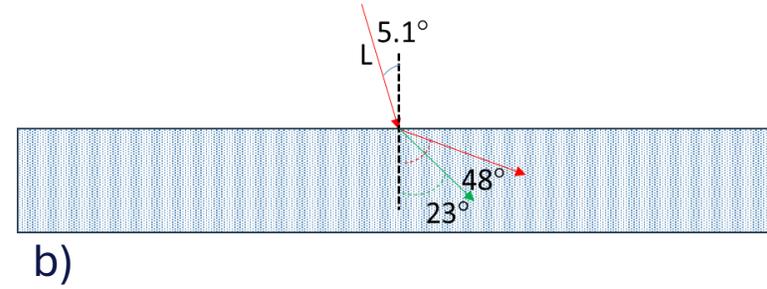
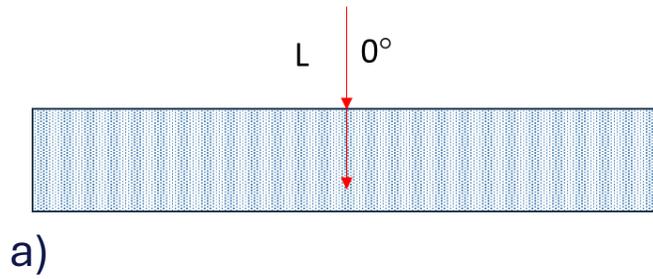
$$T = \frac{4}{2 + 2\cos^2(kd) + \frac{Z_2^4 - Z_1^4}{Z_2^2 Z_1^2} \sin^2(kd)}$$

$$k = \frac{\omega}{v} - i \frac{\pi f_r}{vQ}$$



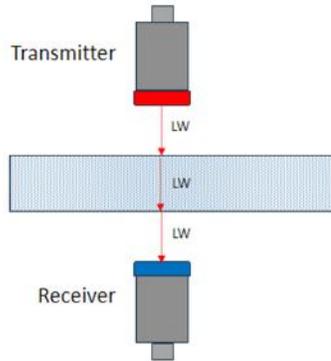
Low coefficient of transmission

# PRINCIPES : Modes de conversion

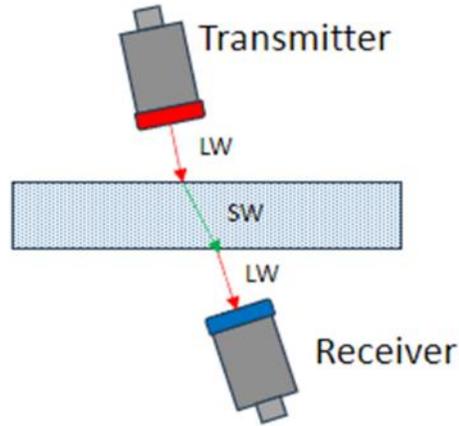


# PRINCIPES : Ultrasons dans l'air

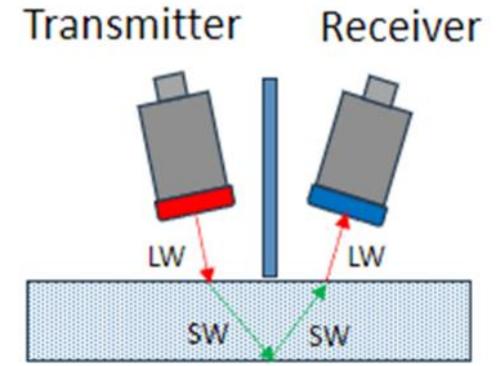
a) Through-transmission compressional wave



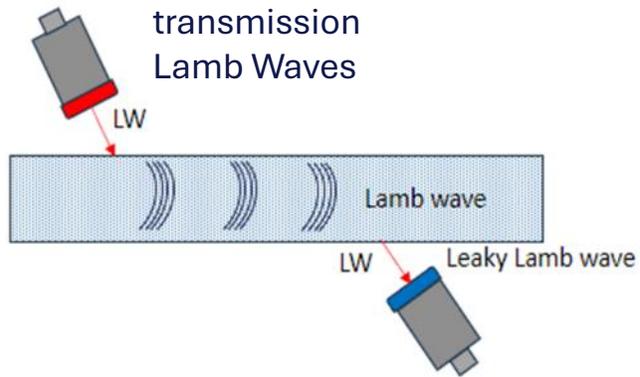
b) Through-transmission shear wave



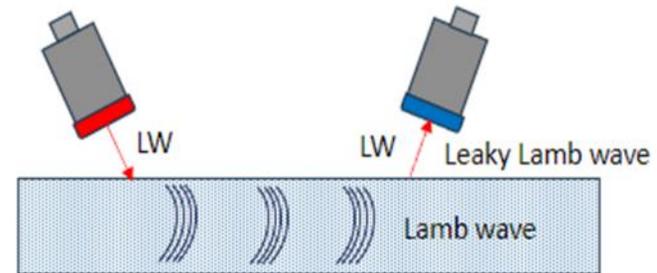
c) Pseudo pulse-echo



d) Through-transmission Lamb Waves



e) Pitch-Catch Lamb wave



# 02 Moyen d'inspection

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Plateforme complète de tests sur échantillon:

- Cobot
- Pilot+
- FastView (logiciel d'acquisition)
- Convertisseur d'encodage

# MOYEN D'INSPECTION : Pilot+ et cobot

**Feasibility Study:** Capacity in our Labs with a Cobot, FastView SW, encoder box and Air Couple Probes  
**UT Board :** Pilot+ parallel multi-channel with AWG capacity (Burst, Chirp, Gaussian, ...)

**Pilot+ Advantage :** High reception dynamic, AWG capacity and Matched Filtering

COBOT



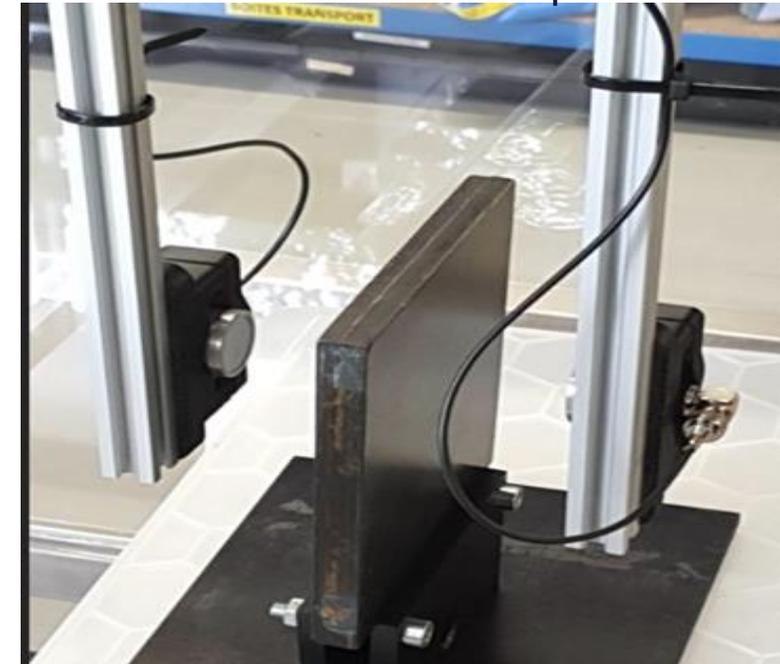
PILOT+/MC2



Encoder convertor

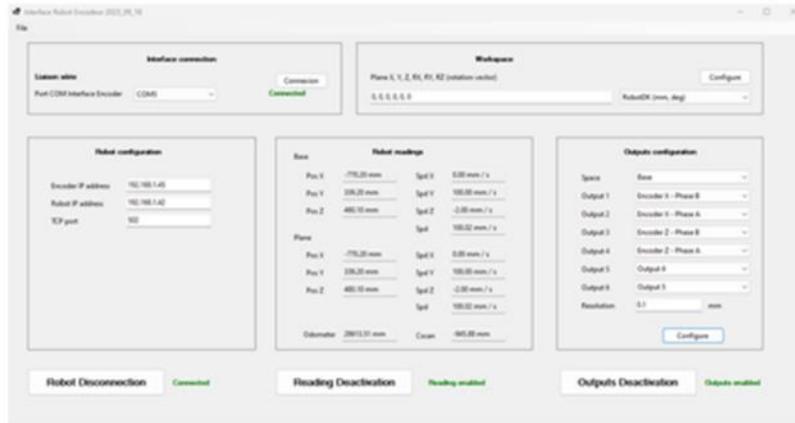


Transducer and part

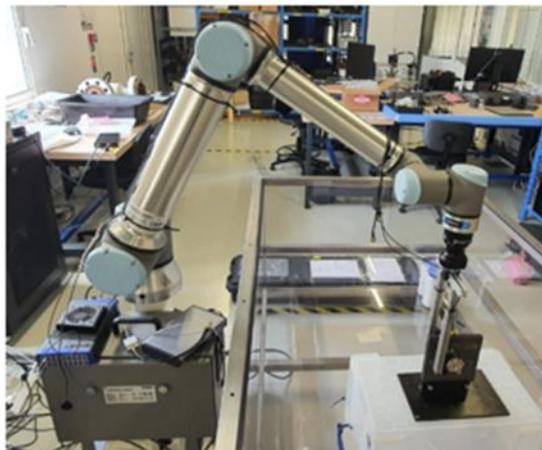
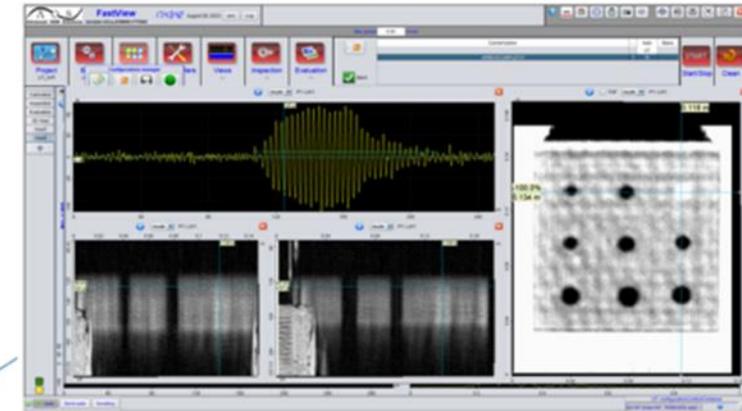


# MOYEN D'INSPECTION

## Interface Robot Encoder



## FastView: UT\_AIR

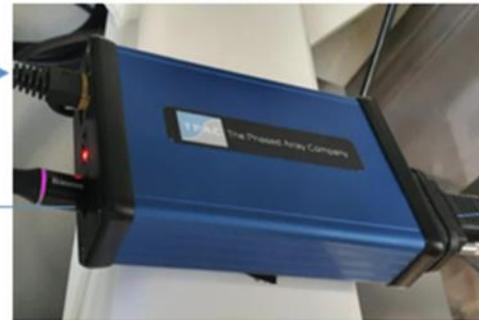


TCP/IP  
X,Y,Z,A,B,C

USB3

PC

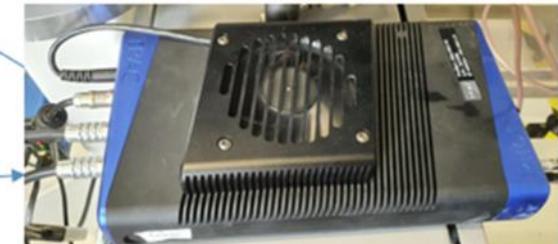
Converter box



TCP/IP

Pilot +

Encoder  
Signal X,Y

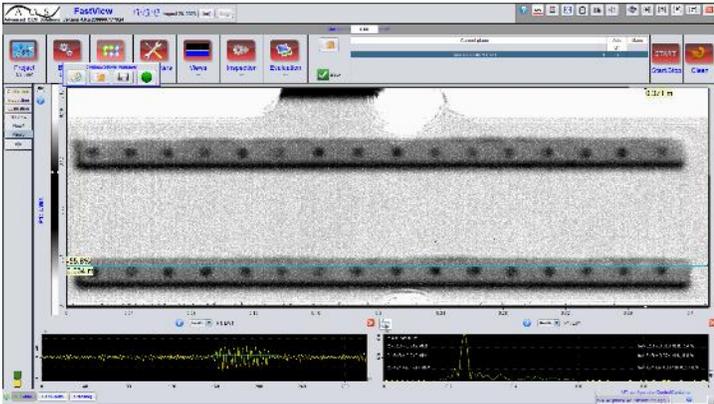
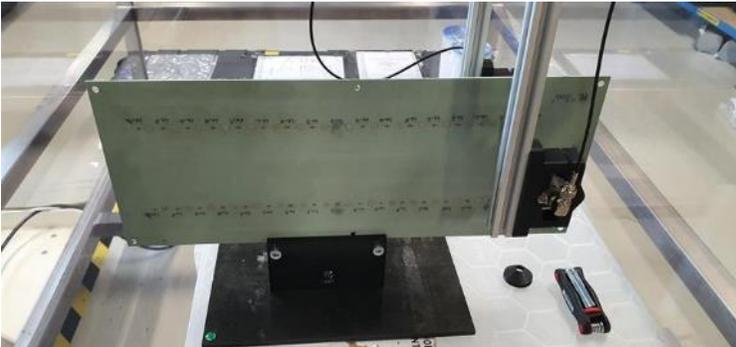


# 03 Essais

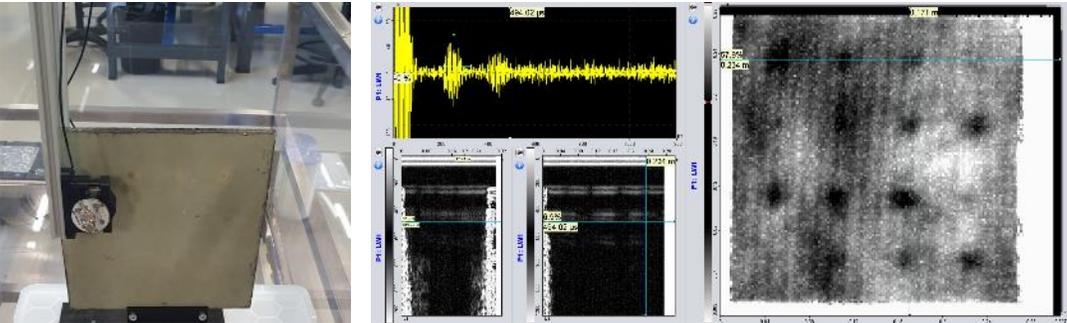
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# CAS D'INSPECTIONS

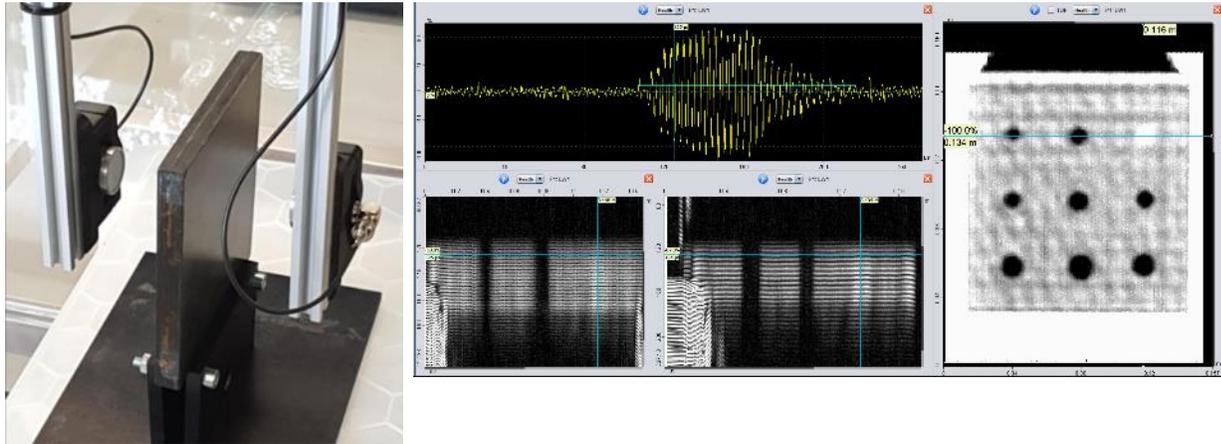
## Glued and riveted aluminum multilayers



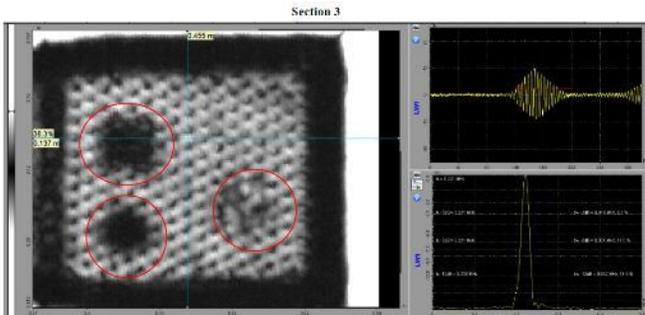
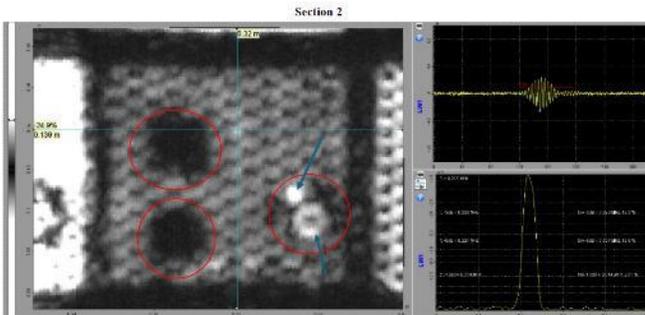
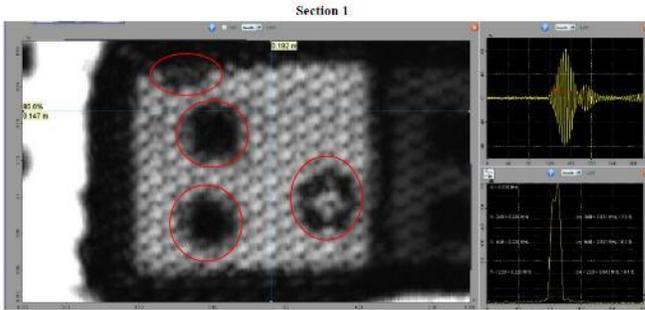
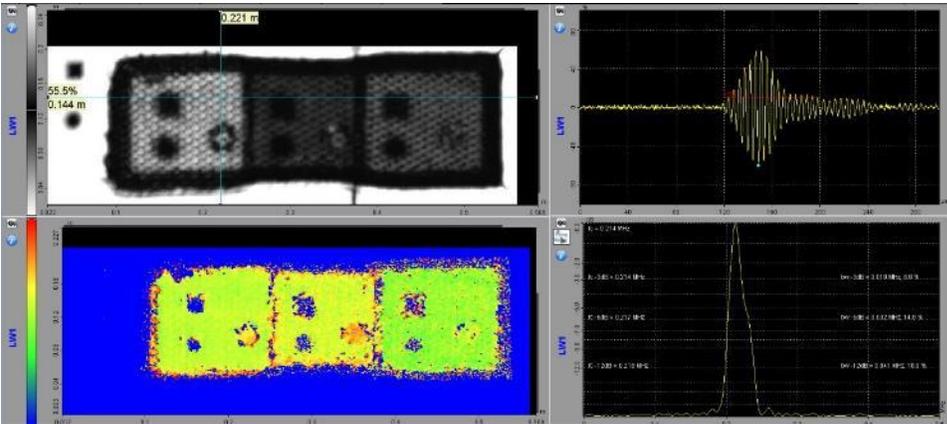
## Honeycomb with artificial defects



## CFRP with artificial defects



# CAS D'INSPECTIONS : Calibration de la sensibilité

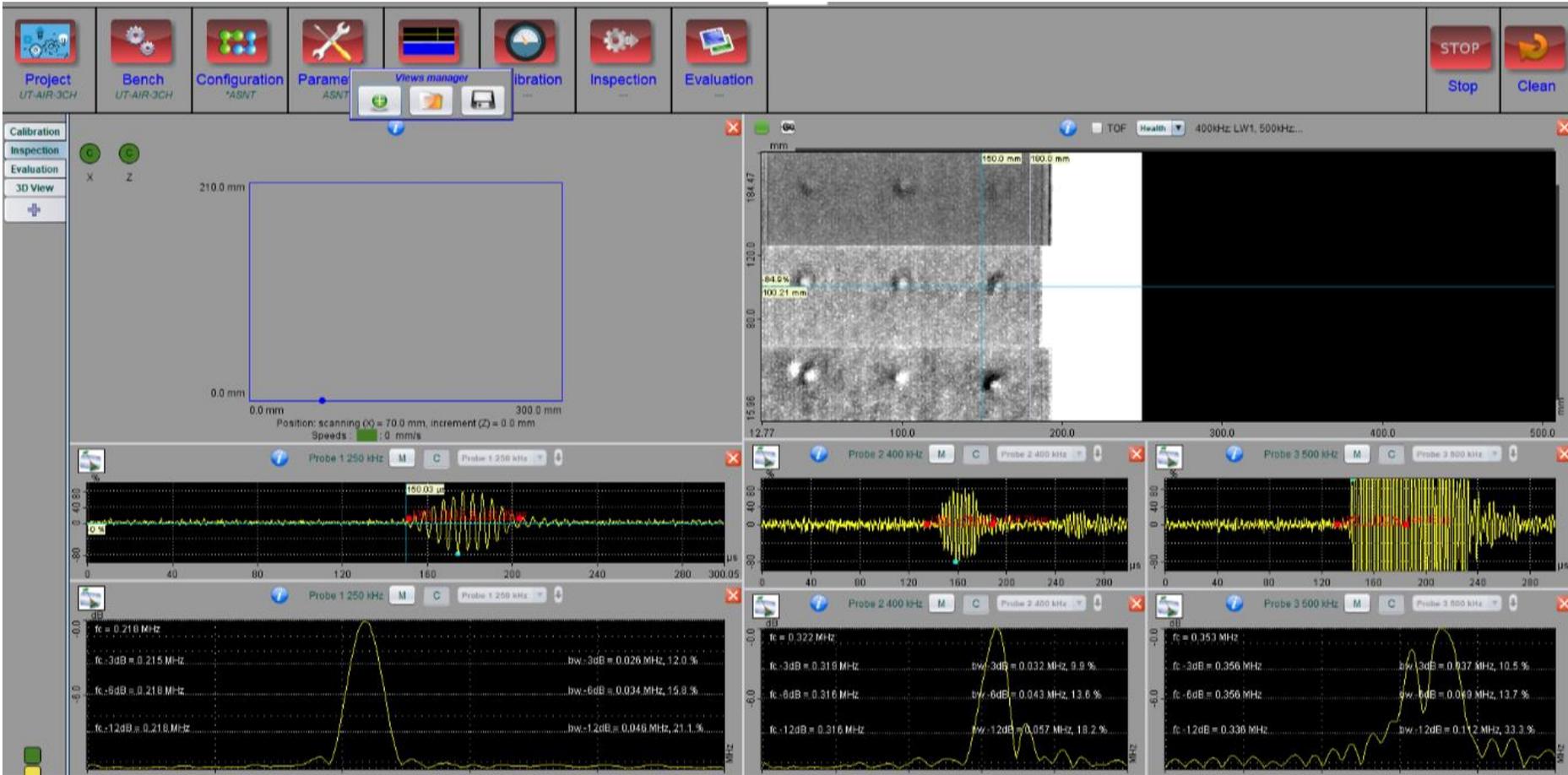
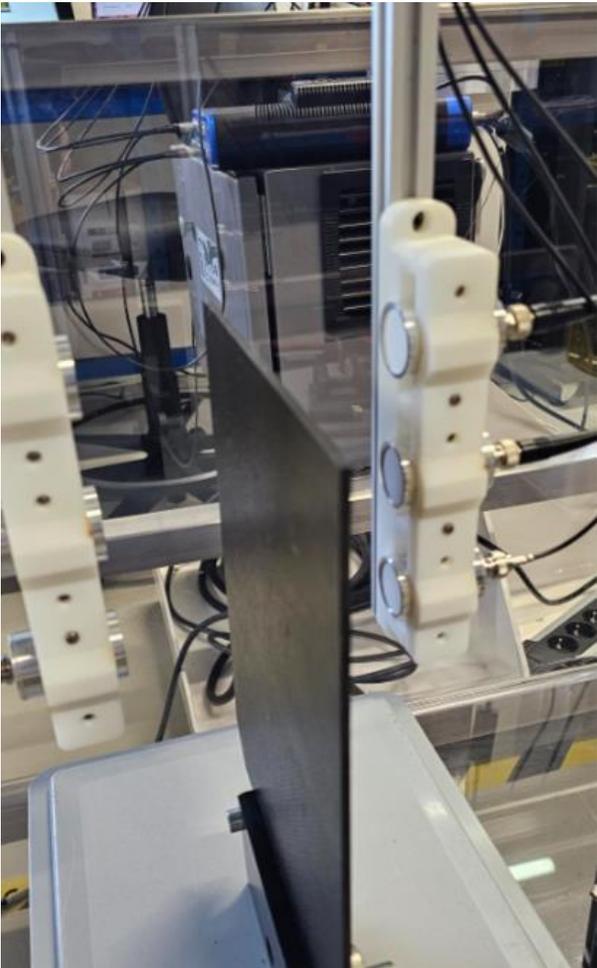


# CONFIGURATION MULTICHANNEL

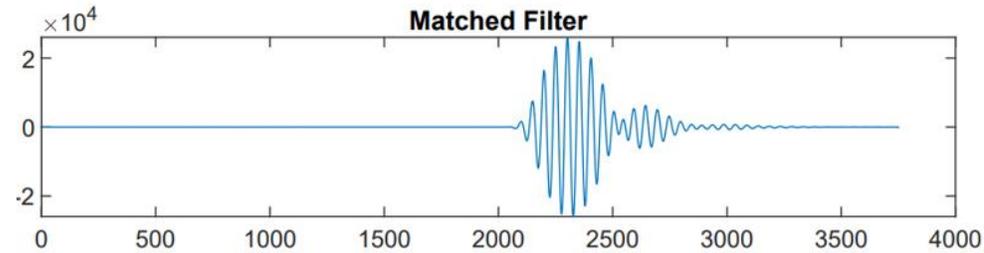
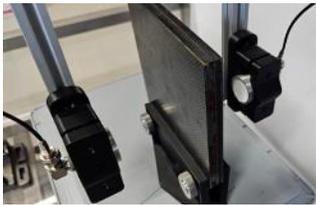


Pilot+ : 8 parallel channel allowing to speed up the inspection

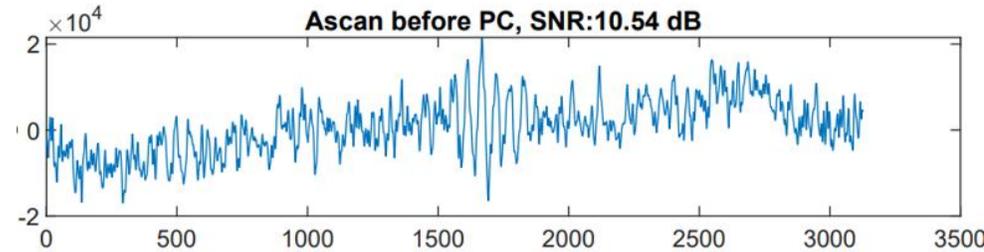
# CONFIGURATION MULTICHANNEL



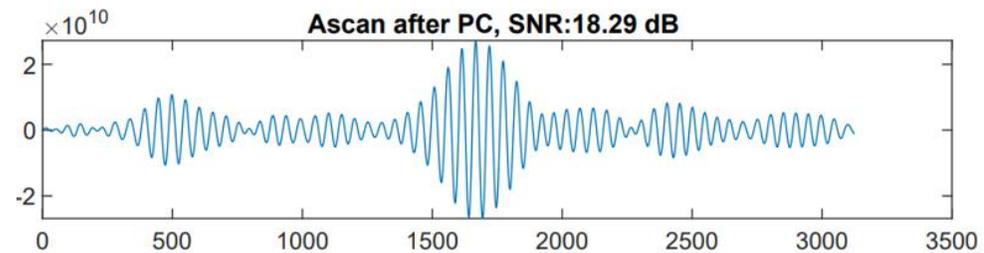
# PRINCIPE : Matched filter



$s(t)$



$$r(t) = s(t) * H(t) + n(t)$$



$$y(t) = \int_{-\infty}^{\infty} r(\tau) s^*(\tau - t) d\tau$$

**Improvement of SNR**

**Allow to replace the averaging decreasing the productivity**

# MATCHED FILTER : Signal Burst



U1 Settings: A-Scan Cumule

0.25 MHz

250.0 μs

300.0 μs

200.0 Hz

166.7 Hz

12.5 MHz

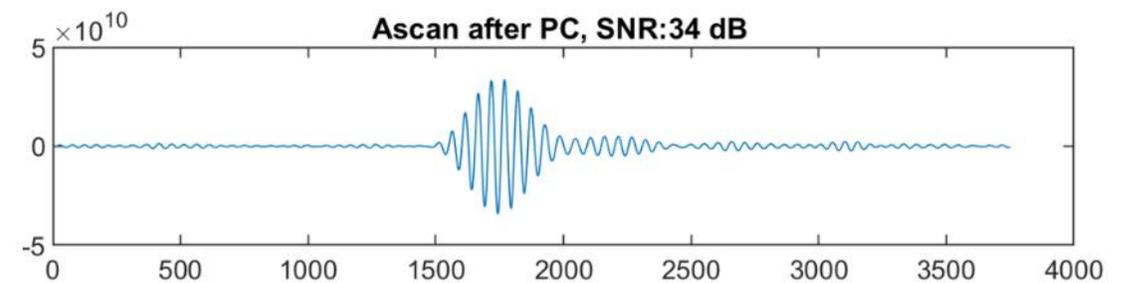
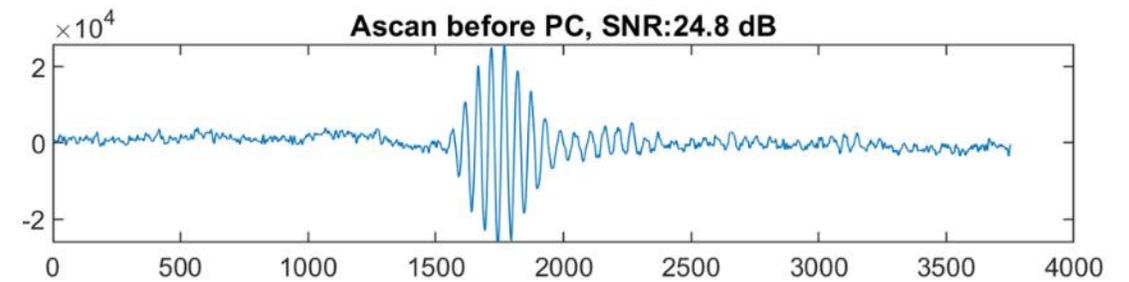
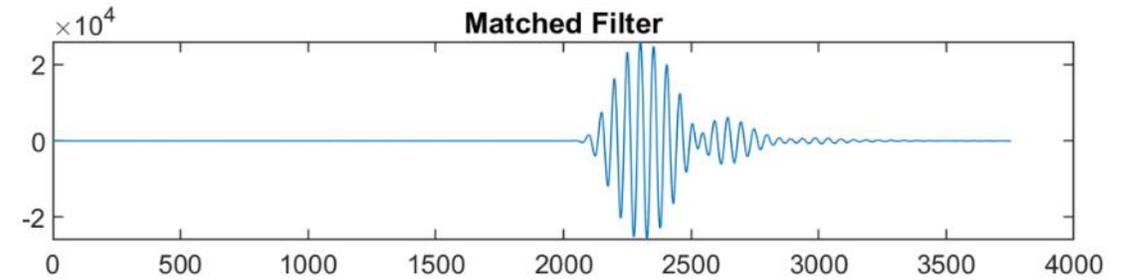
16Bits

SM\_RF

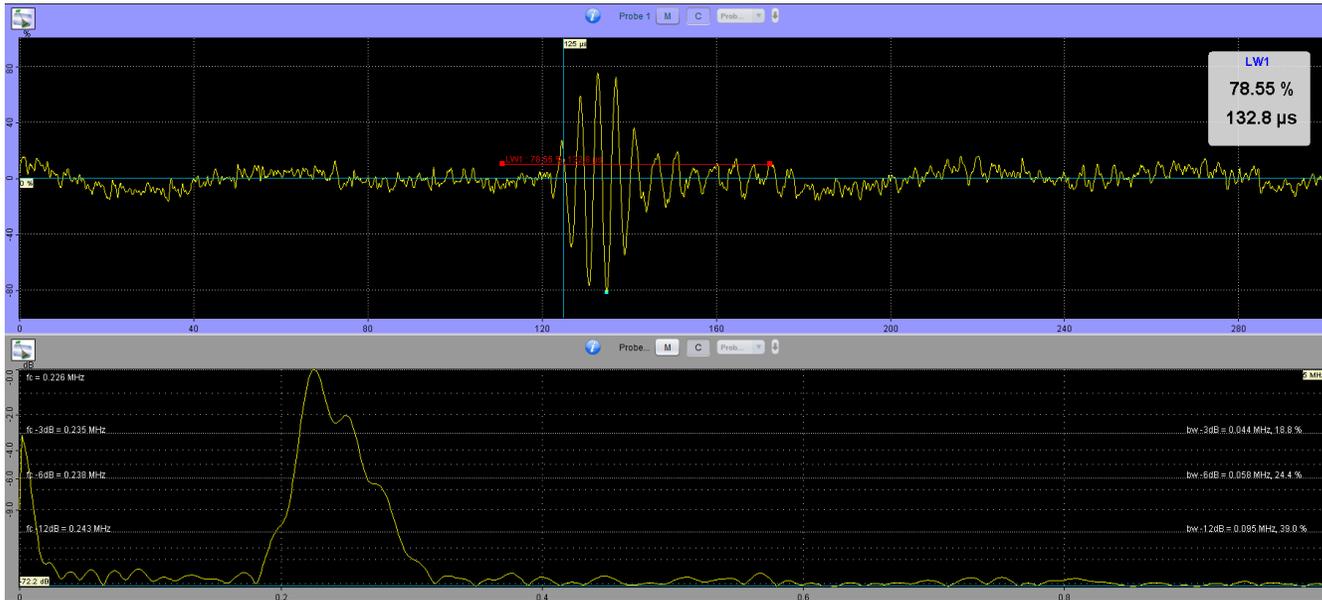
Pulser AWG

Pulse shape BURST

Name	Type	Precision (MHz)	Duration (μs)	F0 (MHz)	Df (MHz)	BWR (%)	Nb cycles	Duty cycles (%)
GAUSSIAN1	GAUSSIAN	10.00	5.12	0.26	0.00	10.00	0	0.00
UNIPOLAR	UNIPOLAR	50.00	5.12	0.25	0.00	0.00	0	0.00
BURST	BURST	10.00	20.48	0.25	0.00	0.00	5	0.00
BIPOLAR	BIPOLAR	10.00	20.48	0.25	0.00	0.00	5	90.00
CHIRP1	CHIRP	10.00	15.36	0.20	1.00	0.00	0	0.00
CHIRP2	CHIRP	10.00	15.36	0.50	1.00	0.00	0	0.00
CHIRP3	CHIRP	10.00	15.36	0.25	1.00	0.00	0	0.00



# MATCHED FILTER : Signal Gaussien



UT Settings: A-Scan Cumule

0.25 MHz

250.0 μs

300.0 μs

200.0 Hz

166.7 Hz

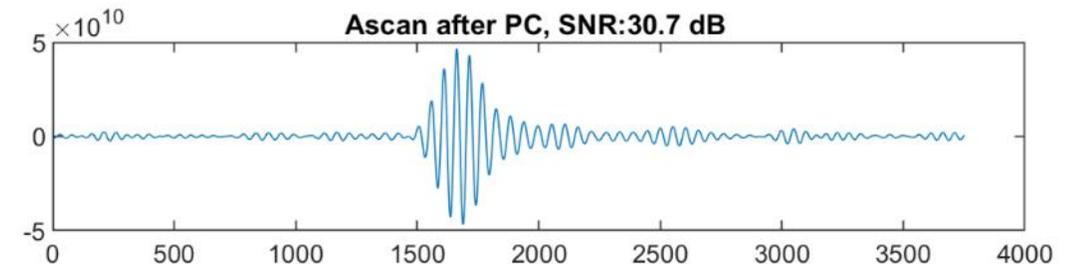
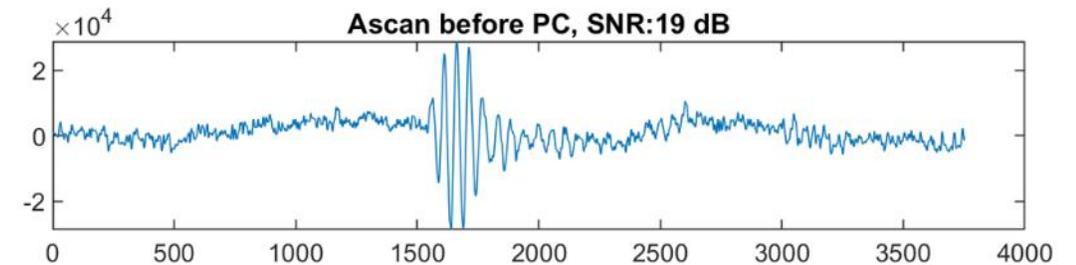
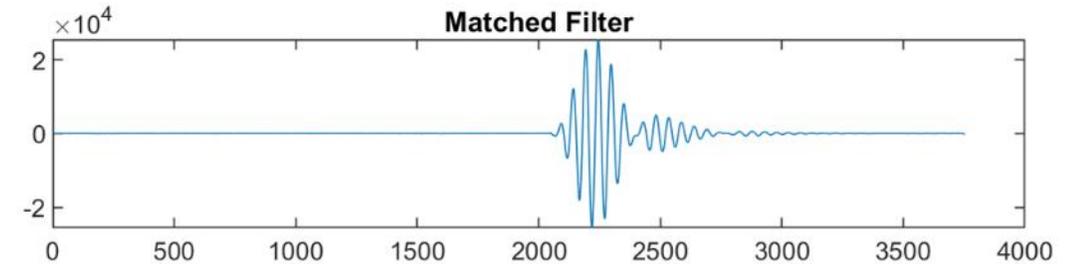
16Bits

SM\_RF

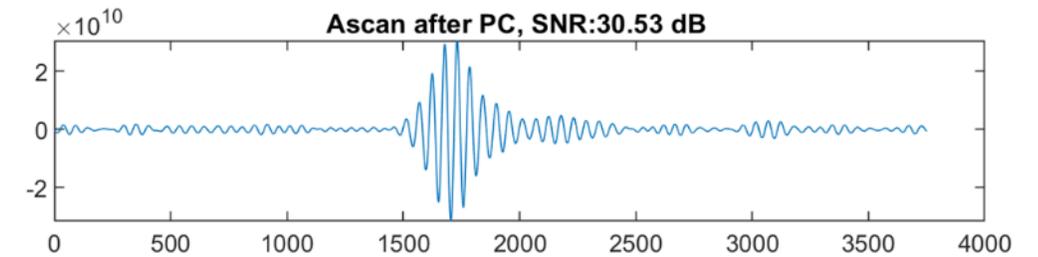
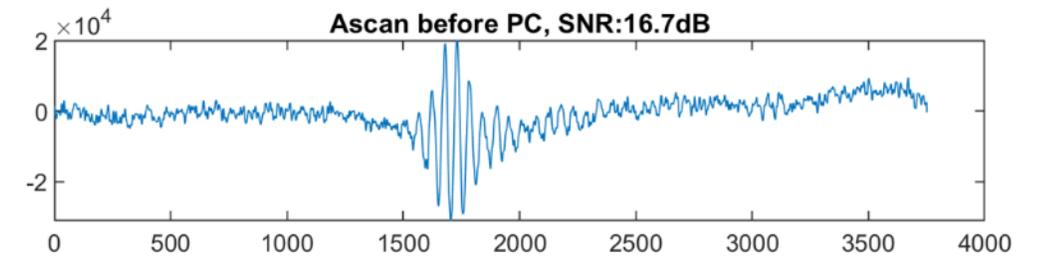
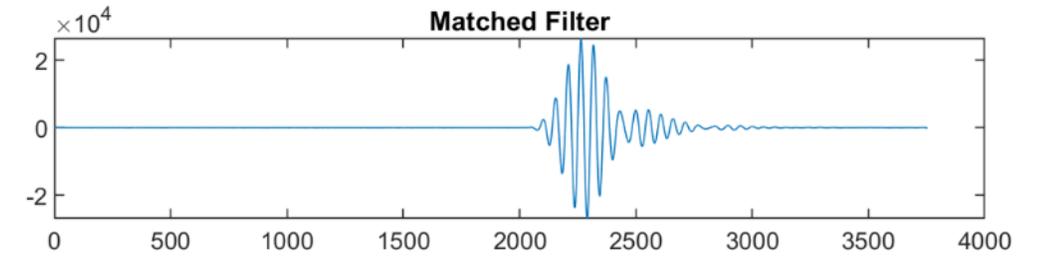
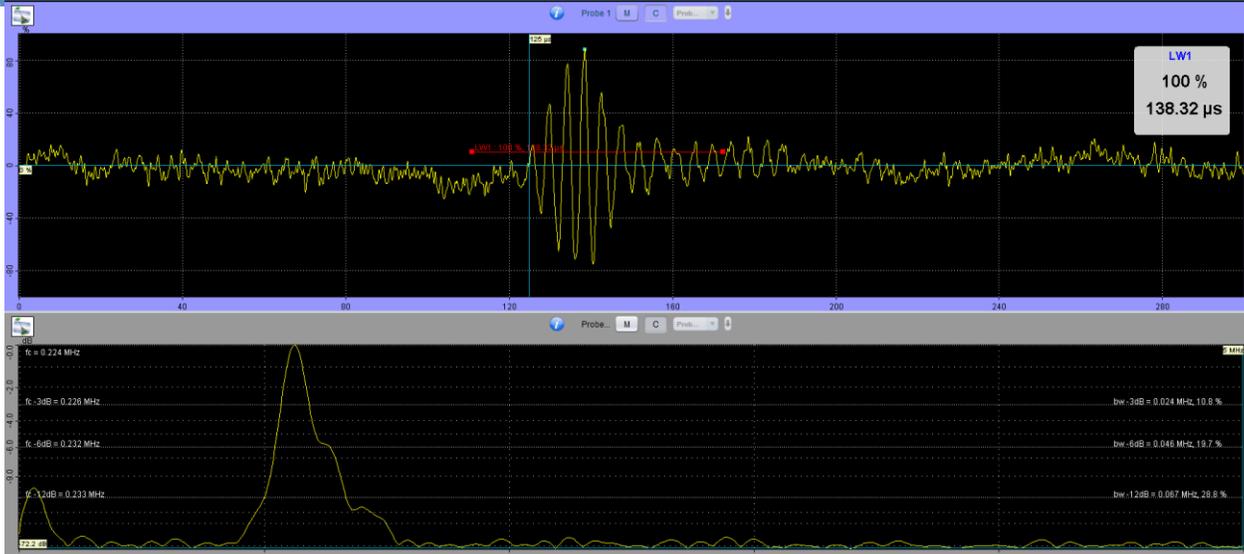
Pulser AWG

Pulse shape GAUSSIAN1

Name	Type	Repetitions (MHz)	Duration (μs)	FC (MHz)	RF (MHz)	BW (MHz)	Nb cycles	Cycle time (μs)
GAUSSIAN1	GAUSSI	10.00	5.12	0.26	0.00	10.00	0	0.00
UNIPOLAR	UNIPOL	50.00	5.12	0.25	0.00	0.00	0	0.00
BURST	BURST	10.00	40.96	0.25	0.00	0.00	10	0.00
BIPOLAR	BIPOLAR	50.00	20.48	0.25	0.00	0.00	5	90.00
CHIRP1	CHIRP	10.00	15.36	0.20	1.00	0.00	0	0.00
CHIRP2	CHIRP	10.00	15.36	0.50	1.00	0.00	0	0.00
CHIRP3	CHIRP	10.00	15.36	0.25	1.00	0.00	0	0.00



# MATCHED FILTER : Signal CHIRP 3 (compression)



UT Settings: A-Scan Cumule

0.25 MHz

250.0  $\mu\text{s}$

300.0  $\mu\text{s}$

200.0 Hz

166.7 Hz

16Bits

SM\_RF

Pulser AWG

Pulse shape CHIRP3

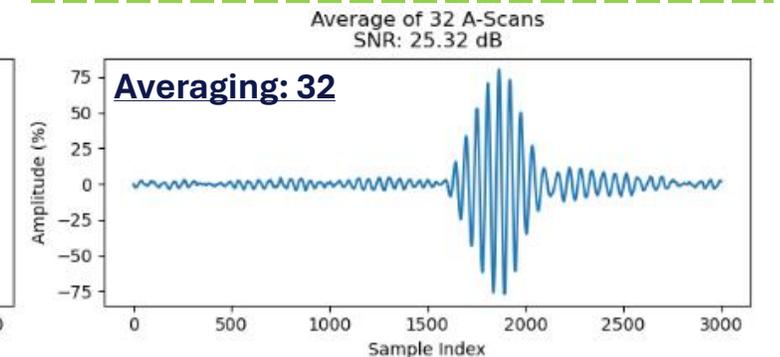
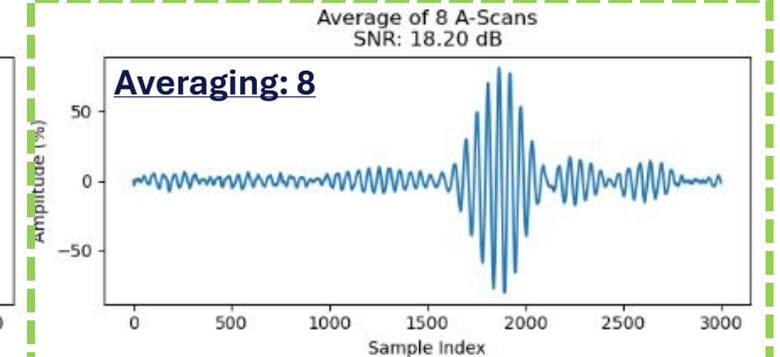
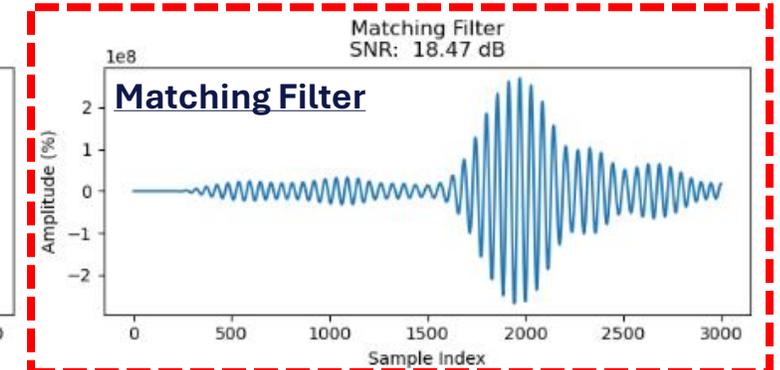
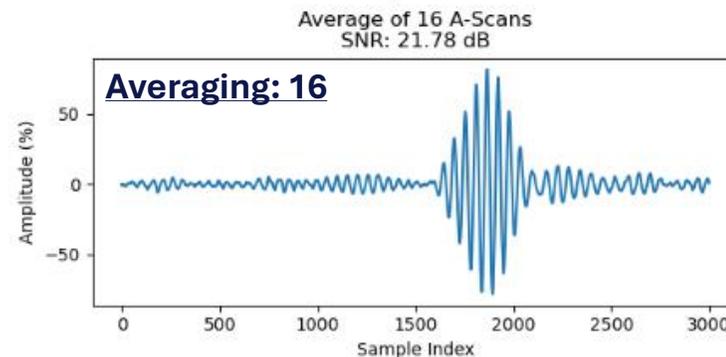
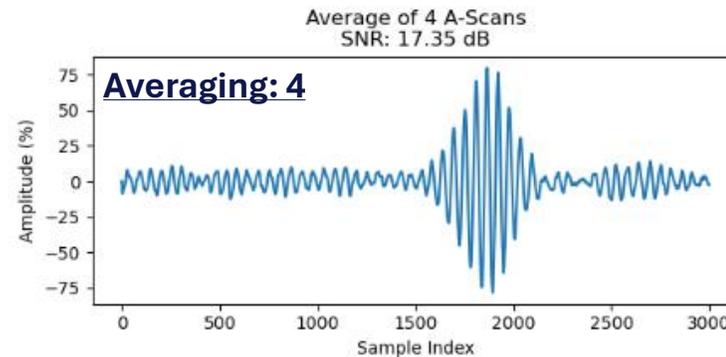
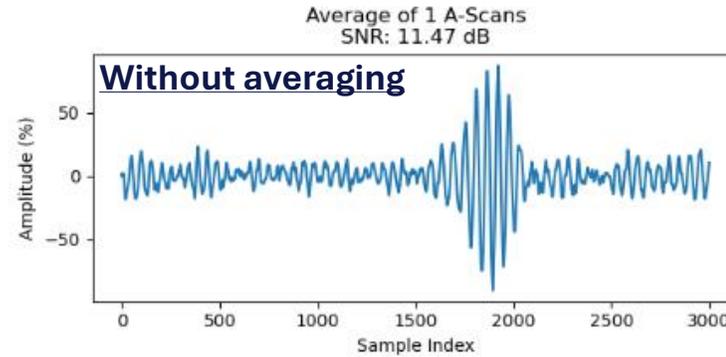
Name	Type	Precision (MHz)	Duration ( $\mu\text{s}$ )	F0 (MHz)	Df (MHz)	BWR (%)	Nb cycles	Duty cycles (%)
GAUSSIAN1	GAUSS...	10.00	5.12	0.26	0.00	10.00	0	0.00
UNIPOLAR	UNIPOL...	50.00	5.12	0.25	0.00	0.00	0	0.00
BURST	BURST	10.00	20.48	0.25	0.00	0.00	5	0.00
BIPOLAR	BIPOLAR	10.00	20.48	0.25	0.00	0.00	5	90.00
CHIRP1	CHIRP	10.00	15.36	0.20	1.00	0.00	0	0.00
CHIRP2	CHIRP	10.00	15.36	0.50	1.00	0.00	0	0.00
CHIRP3	CHIRP	10.00	15.36	0.25	1.00	0.00	0	0.00

# MATCHED FILTER : Matched filtering Vs Moyennage

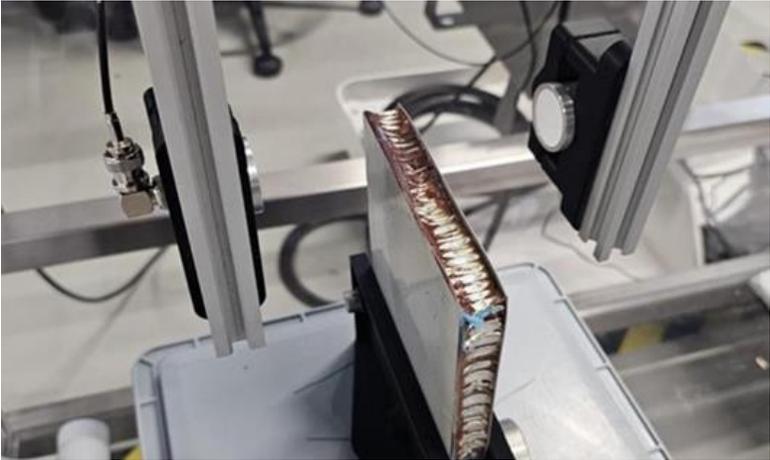
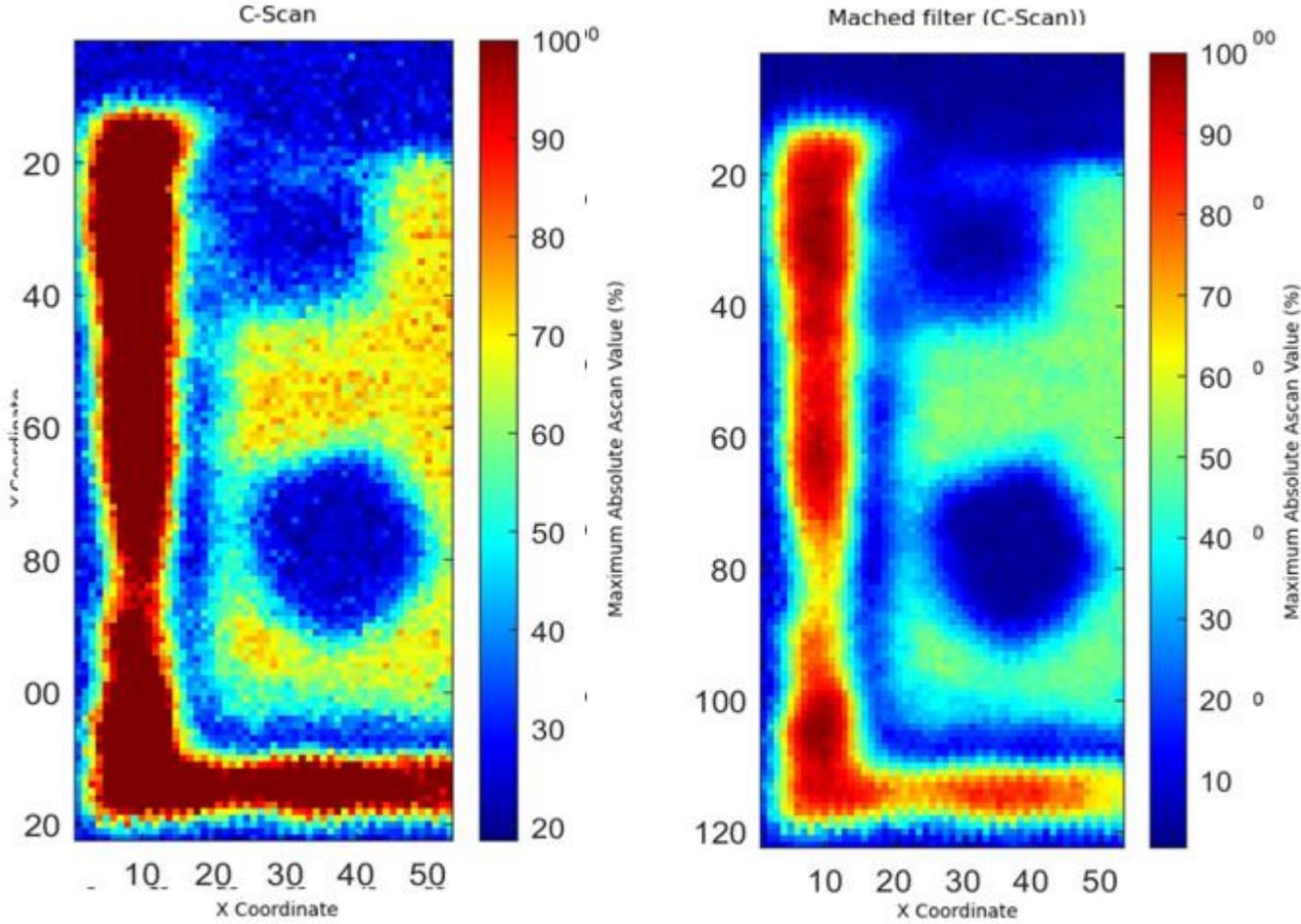


Improvement of SNR

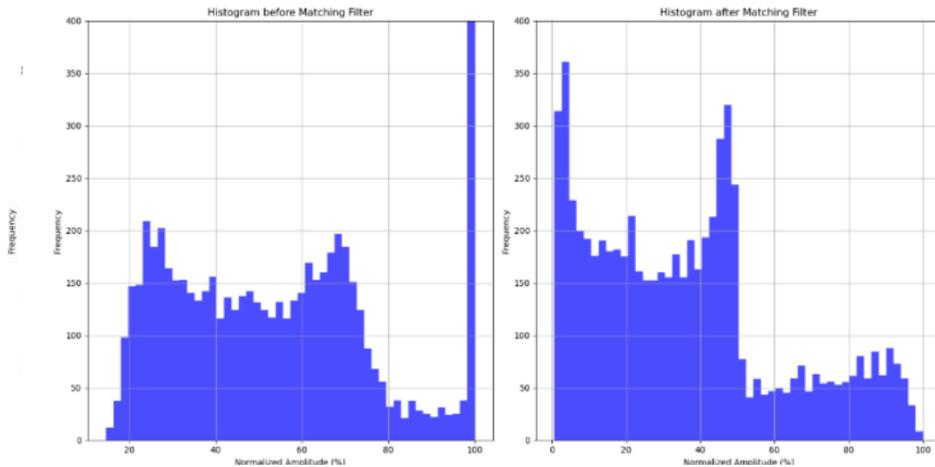
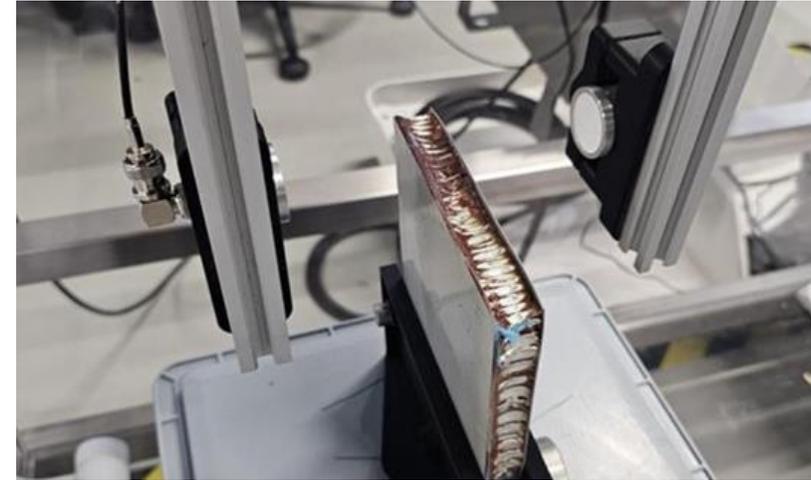
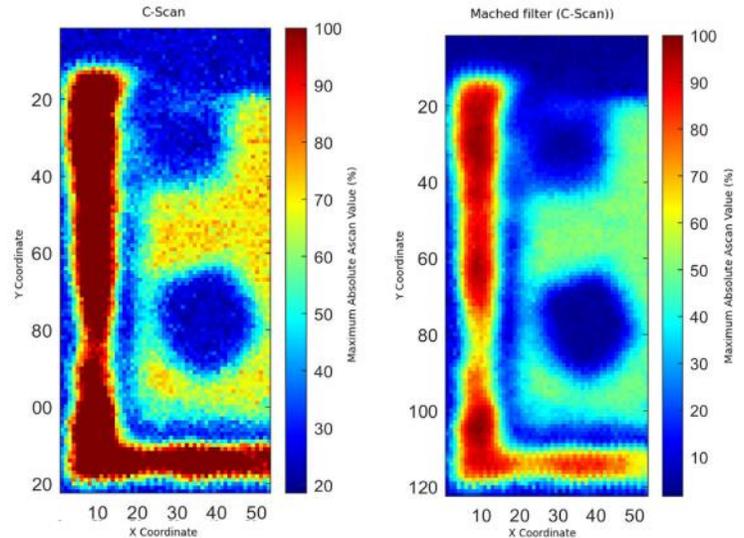
Matching Filter equivalent to averaging 8  
=> 1 firing Vs 8 => faster inspection



# MATCHED FILTER : Exemple C-Scan



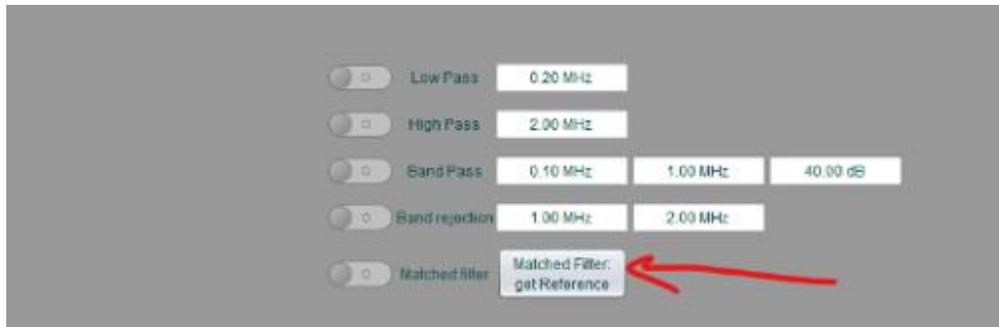
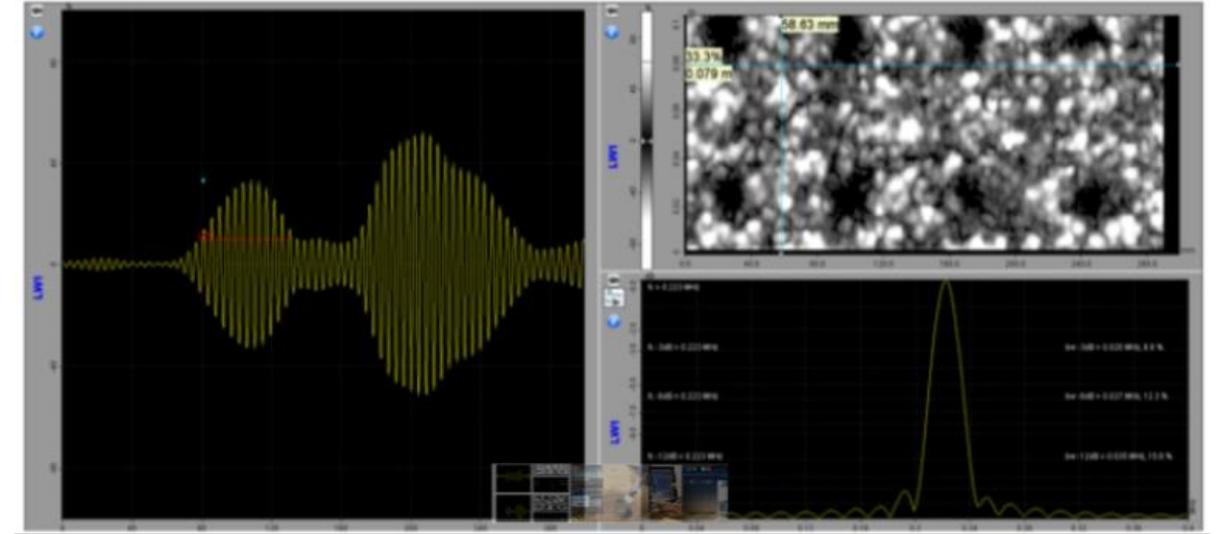
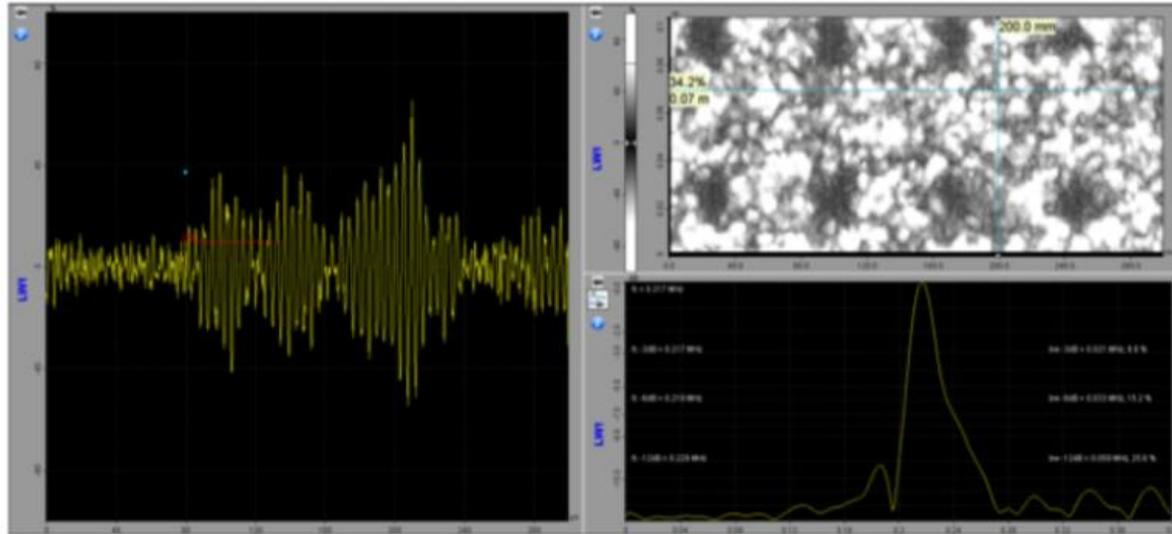
# MATCHED FILTER : Exemple C-Scan



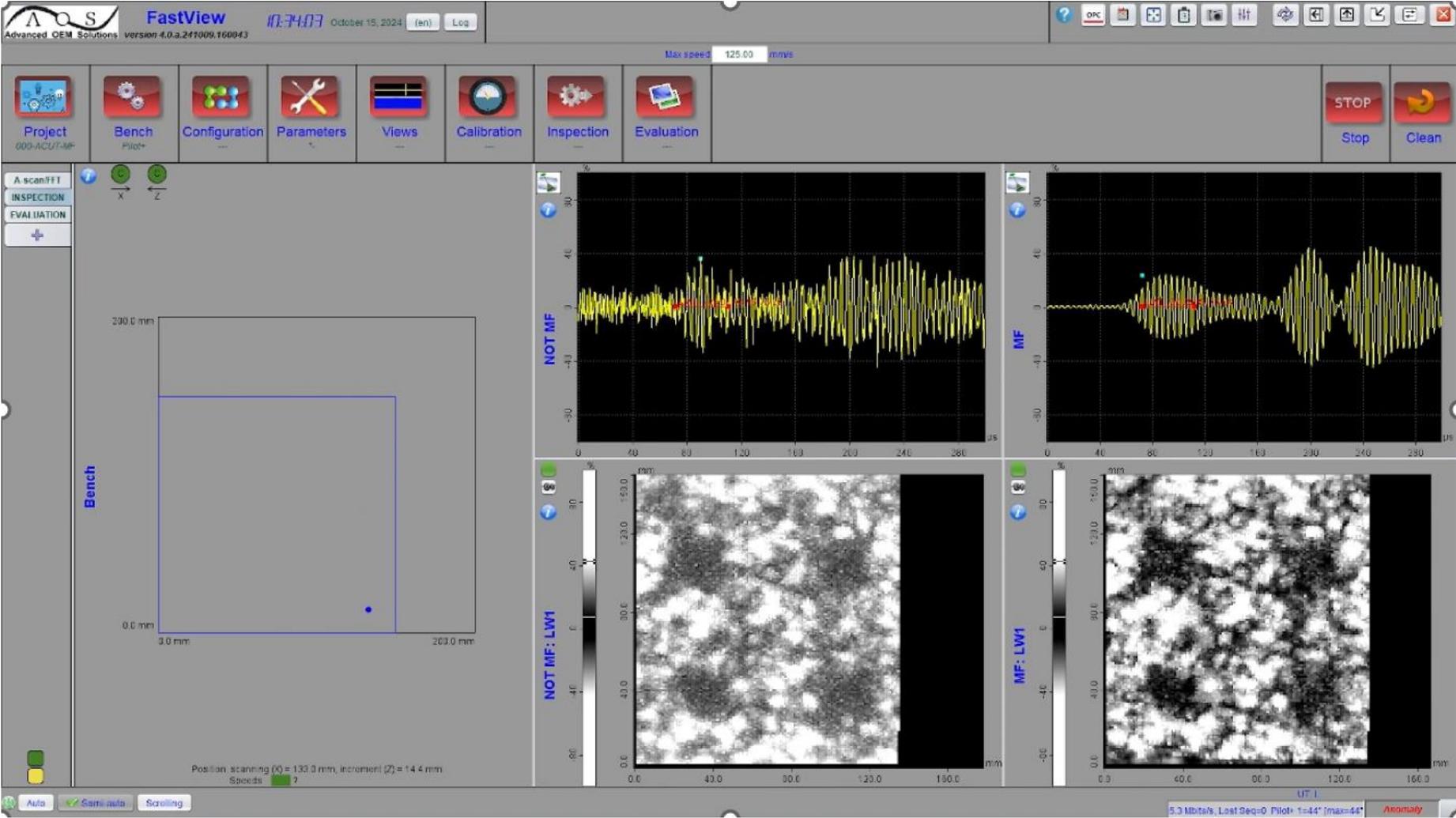
In the c-scan it is difficult to appreciate the effect of the SNR directly, but it translates into better contrast in the image. That is why we present it with the histogram, where a modification can be seen in the amplitude populations of the pixels.

**Contrast Improvement**

# MATCHED FILTER : Inspection avec logiciel FastView



# MATCHED FILTER : Inspection en vidéo



# 05 Conclusions

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- Pilot + with High Dynamic receiver + AWG: allow to do Air Couple inspection
- FastView : allow the setting and inspection using encoder
- Matching Filter in case of low SNR:
  - Solution to replace the averaging
  - Solution to speed up the inspection
- Productivity : possibility with Pilot+ to do multi-probe inspection

**CONFIDENTIAL**



# Merci

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