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Intended for: Example of LANL research to show college professors in the hopes of earning a research position or fellowship position

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2016 Research

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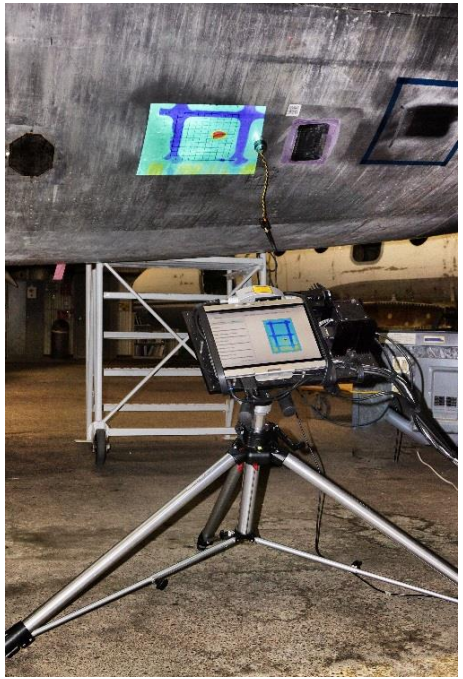
Acoustic Wavenumber Spectroscopy

- used as a nondestructive evaluation technique
- transducer provides single-tone steady-state excitation to specimen being examined
- laser Doppler vibrometer (LDV) takes raster scan of moving part and records complex-valued velocity response
- from there, we can analyze amplitude, phase, and wavenumber of spatial response



AWS inspection of Boeing 737

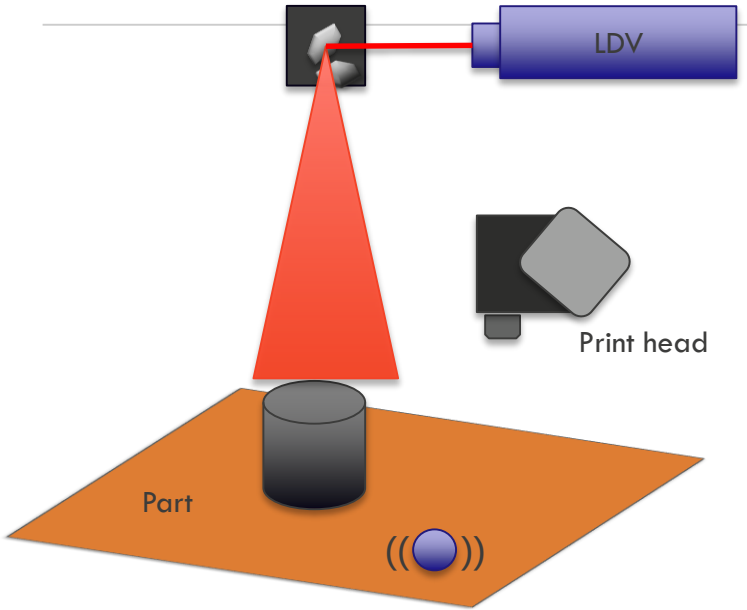
1. In-process inspection for additive manufacturing
2. AWS inspection of complex geometries- scanning at oblique angles
3. Nondestructive evaluation of aerospace composite materials

1

Additive Manufacturing

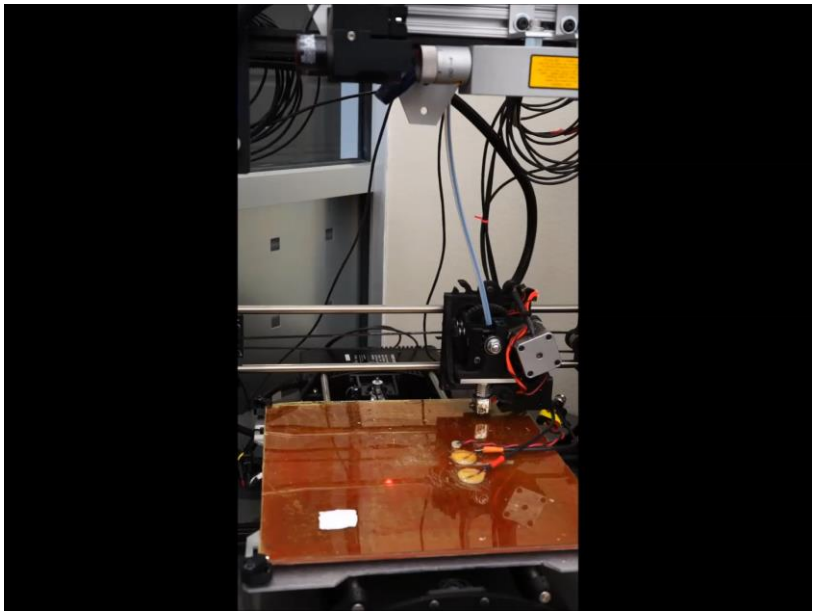
3D-Printing Inspection

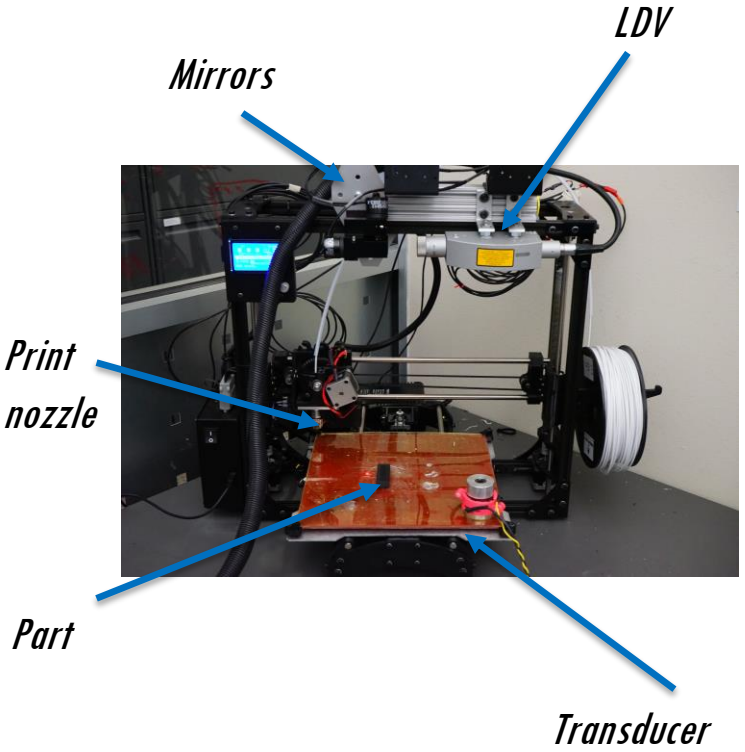
- Currently 25% of post-manufacturing process is spent on inspection (NASA)
- Develop fast, layer-by-layer inspection technique to minimize cost and effort
- Altered g-code of 3D-printer
  - Inserted python script for AWS scan



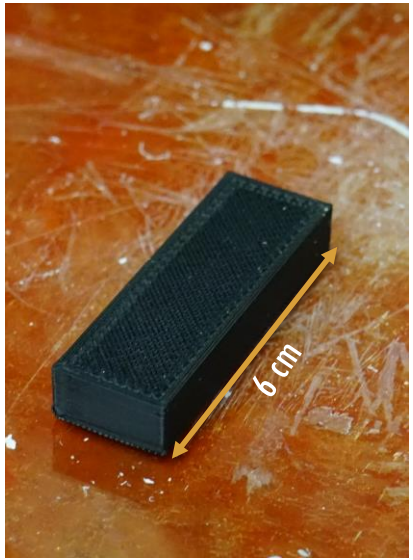
Between layers, the print head is removed from the 3D-printed part so that the LDV can take a raster scan of the part's surface layer.

Experimental Setup



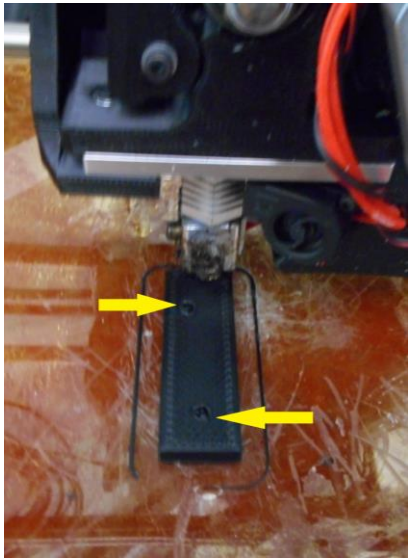


Introducing Damage



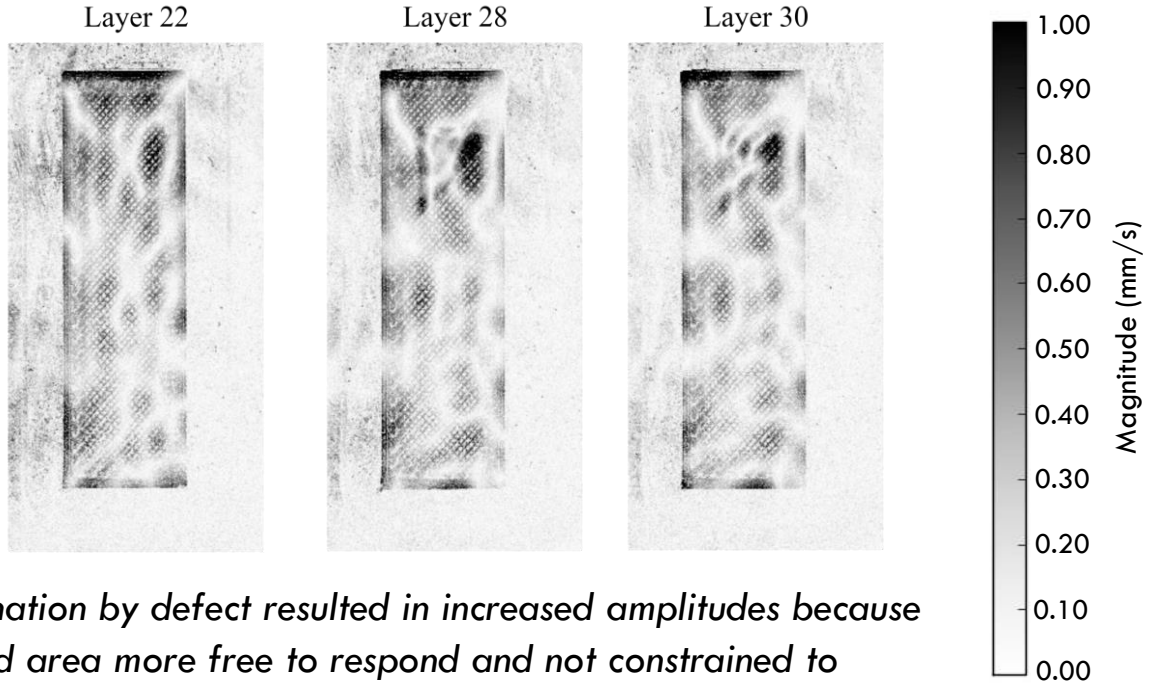
“Healthy” print

Foreign object damage print



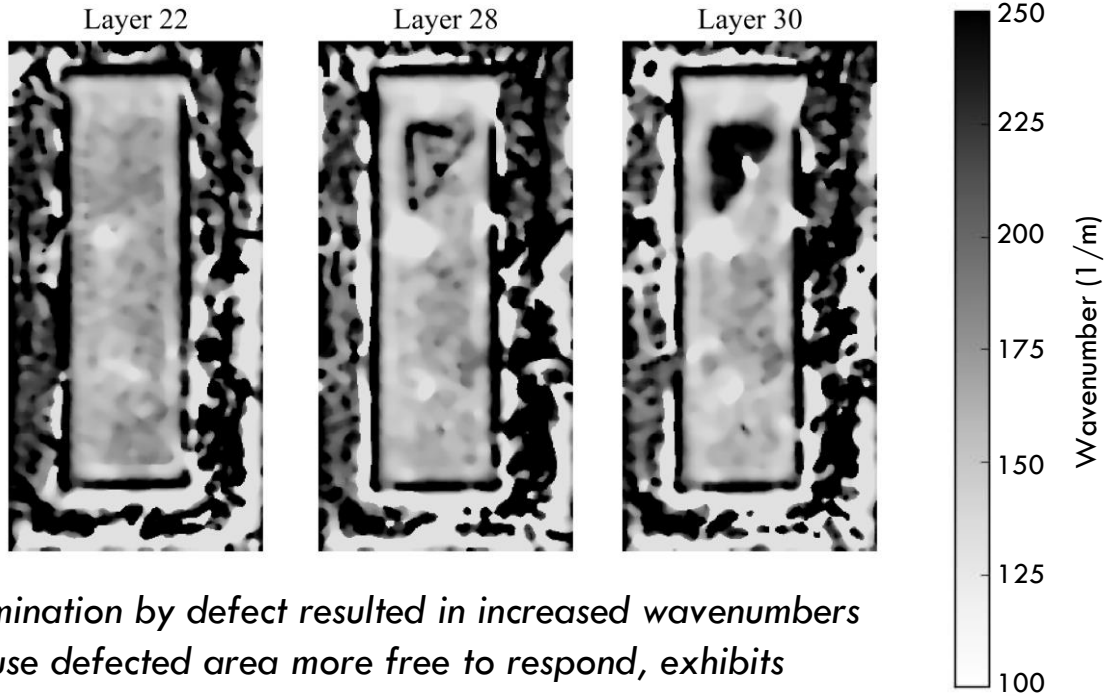
Localized heating damage print

Detecting Damage using Amplitude



Delamination by defect resulted in increased amplitudes because defected area more free to respond and not constrained to greater mass and greater stiffness of 3D-printed part

Detecting Damage using Wavenumber



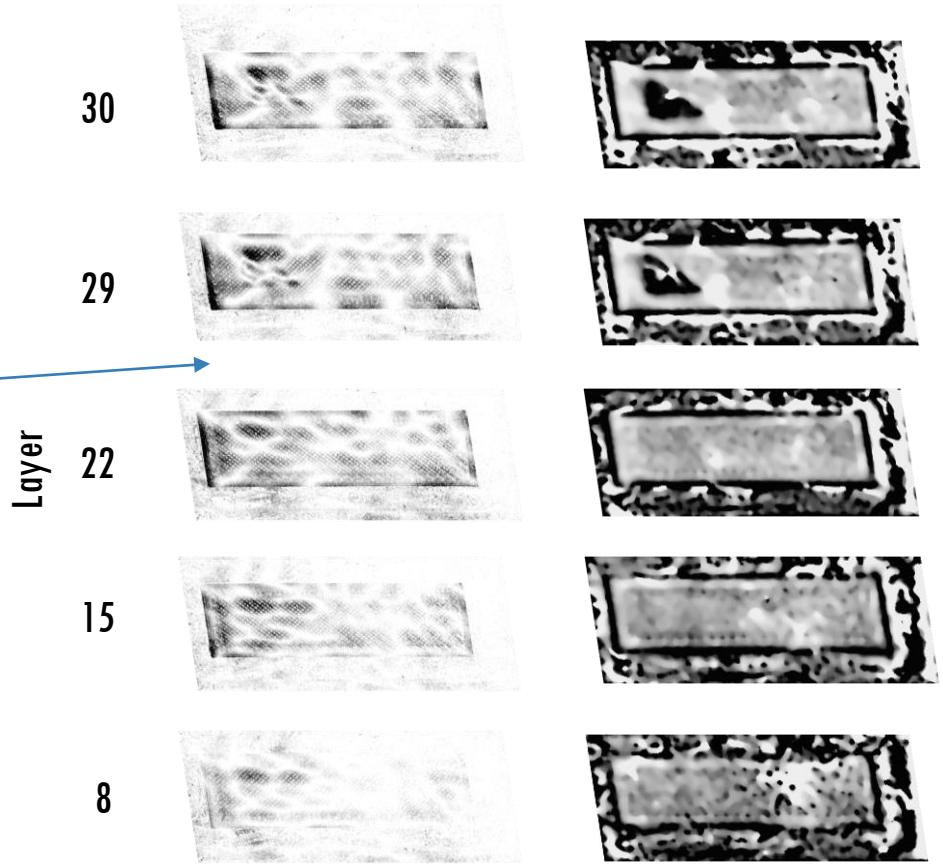
Delamination by defect resulted in increased wavenumbers because defected area more free to respond, exhibits decreased stiffness, and lower mass

Results

Foreign Object Damage Print

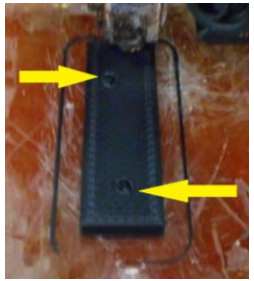
- Damage introduced in 27th layer
- Seen in amplitude plots from 27th to 35th layers
- Wavenumber plots from 27th layer to 39th layer

Damage introduced between these layers



Results
Localized Heating Damage Print

- Damage introduced in 20th layer
- Seen in amplitude plots from 20th to 31st layers
- Wavenumber plots from 20th layer to 34th layer



Damage introduced between these layers

Layer

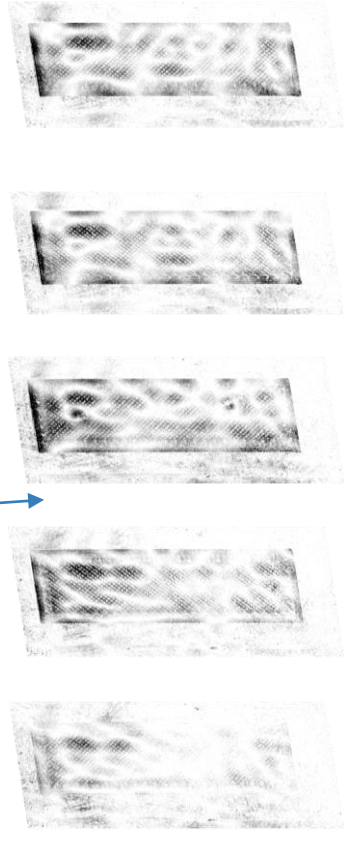
30

29

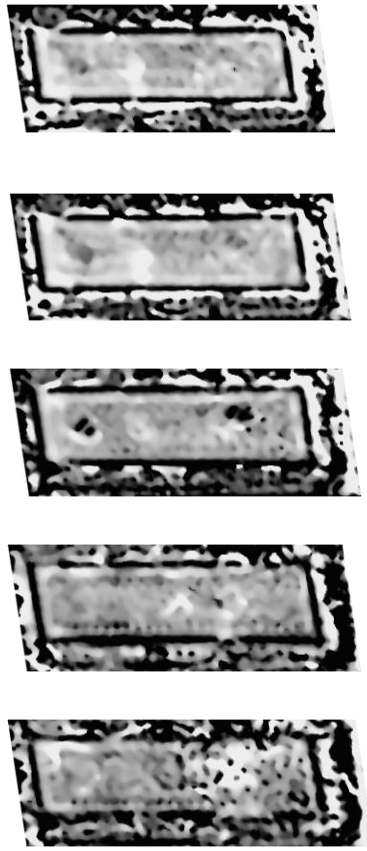
22

15

8



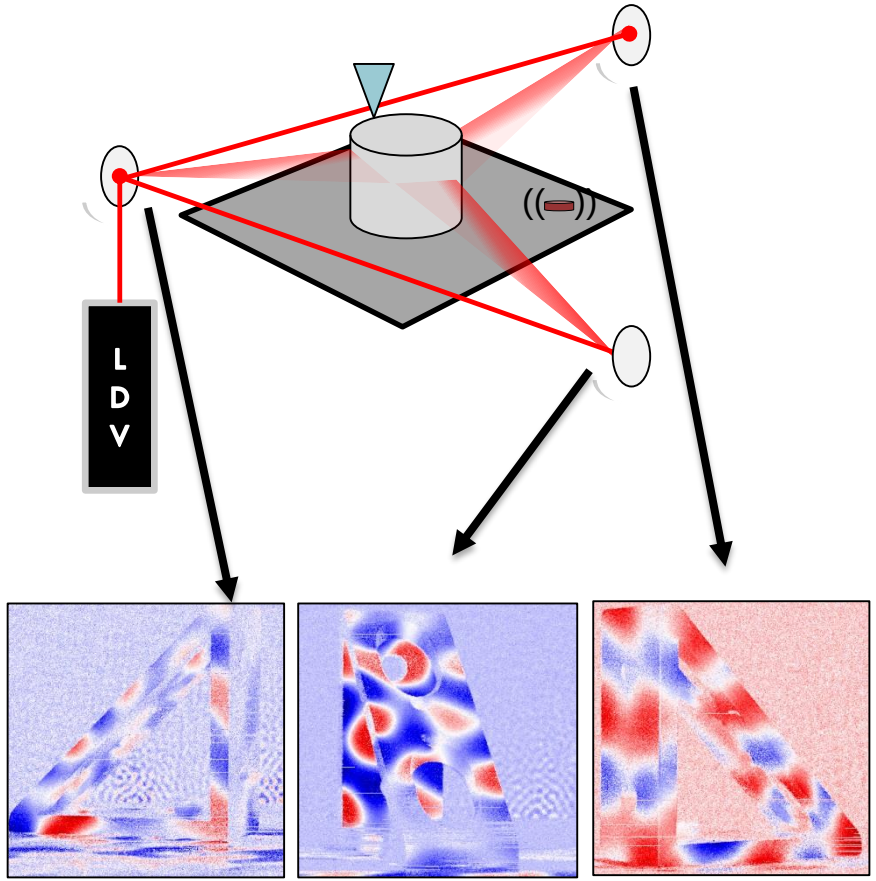
Amplitude (mm/s)



Wavenumber (1/m)

Summary and Future Investigations

- Amplitude provides most accurate lens as to size, shape, and nature of given defect
- Wavenumber can detect damage in later layers of print
- AWS can provide layer-by-layer in-process inspection for additive manufacturing
- In future, would like to investigate use of multiple scanning mirrors to provide 360° inspection

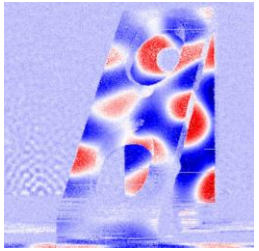


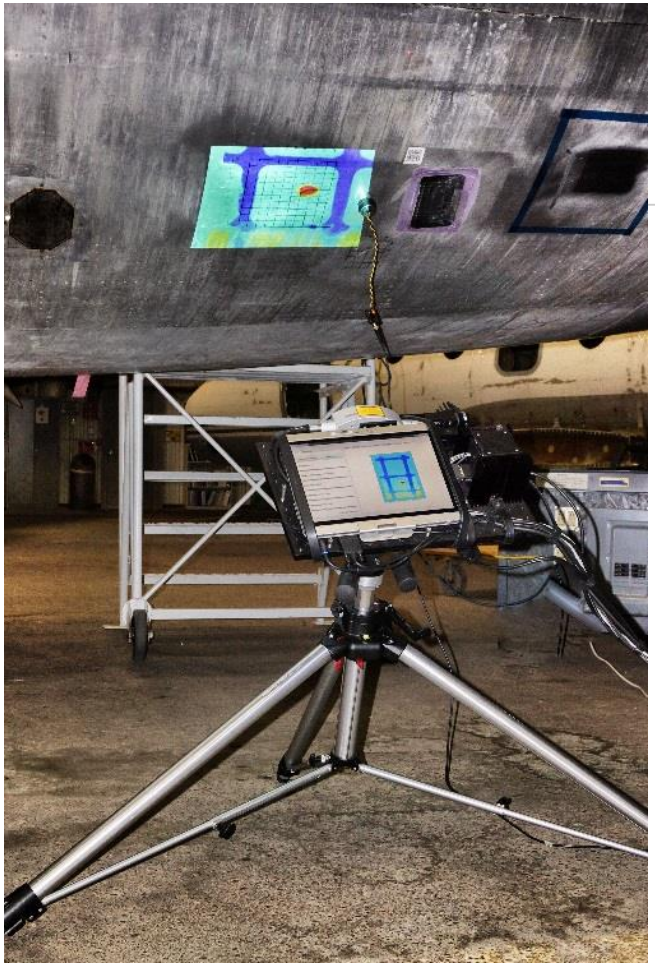
2

Scanning at Oblique Angles

Perspective Projection and Interpolation

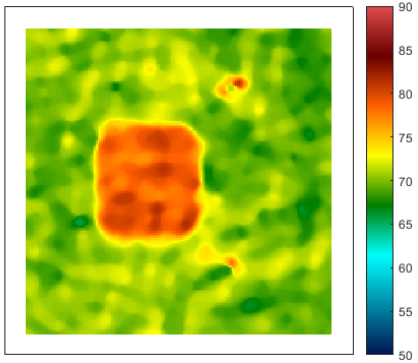
- Goal is to scan more complex geometries:
  - 3D-printed components
  - Beams/joints
  - Round surfaces



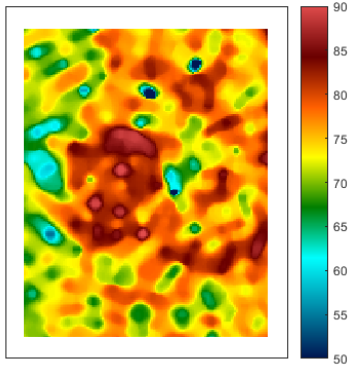


The Problem

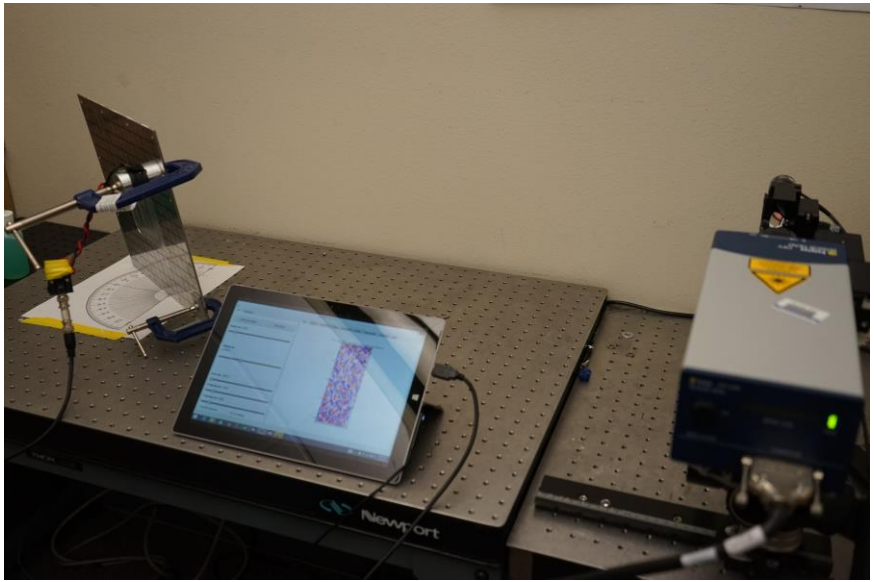
- scans taken at non-normal incidence angle result in skewed wavenumber responses due to perspective



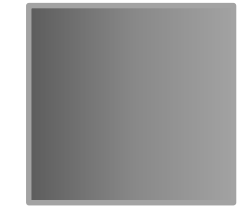
Damaged sample #3 scanned at 0° incidence angle



Damaged sample #3 scanned at 30° incidence angle

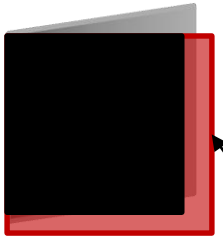


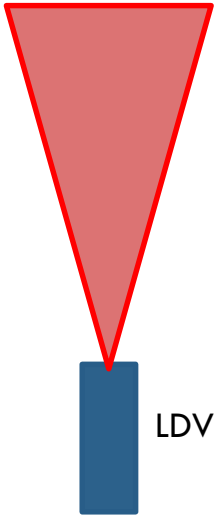
Damaged sample #3 scan setup at 60° incidence angle



1 Define the scanned object in 3d space

2 Translate and rotate object to actual distance and angle from LDV





LDV

Scan region

3 Find 2D perspective projection of object at normal incidence angle

4 Interpolate at perspective projection coordinates within the original “skewed” scan

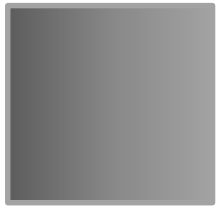
It turned out to be a multistep problem.

Translate and rotate

2 $M = G * T$

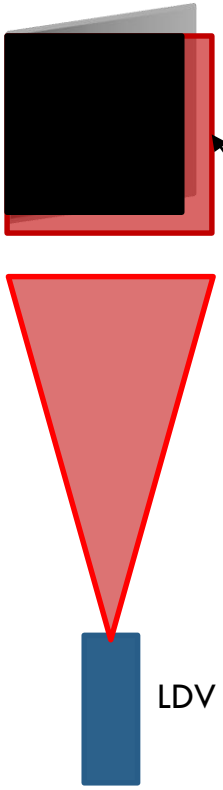
$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\alpha & sin\alpha \\ 0 & -sin\alpha & \cos\alpha \end{bmatrix} * \begin{bmatrix} cos\beta & 0 & -sin\beta \\ 0 & 1 & 0 \\ sin\beta & 0 & cos\beta \end{bmatrix} * \begin{bmatrix} cos\gamma & sin\gamma & 0 \\ -sin\gamma & cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$T = \begin{bmatrix} R_{1,1} & R_{1,2} & R_{1,3} & 0 \\ R_{2,1} & R_{2,2} & R_{2,3} & 0 \\ R_{3,1} & R_{3,2} & R_{3,3} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 & Xoffset \\ 0 & 1 & 0 & Yoffset \\ 0 & 0 & 1 & -range \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



1 Define the scanned object in 3d space

$G = (x, y, z)$



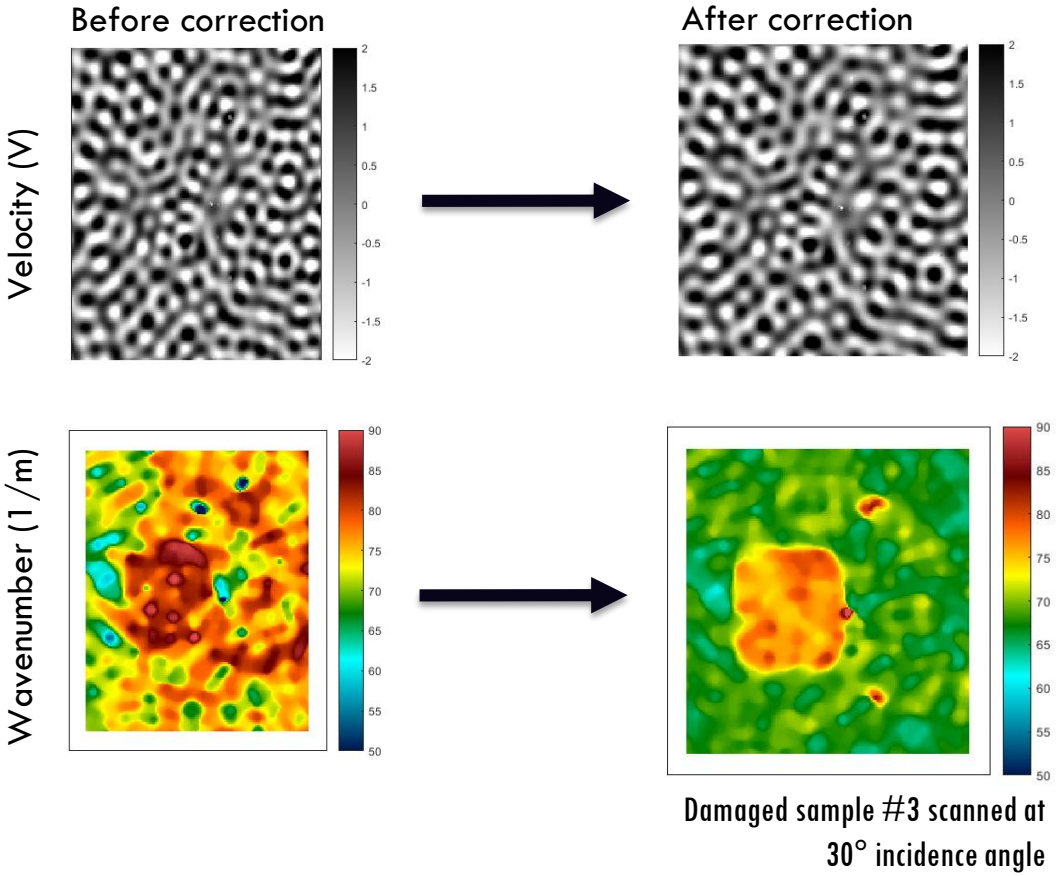
Scan region

3 Find 2D perspective projection

$$PROJarray = \begin{bmatrix} -range & 0 & 0 & 0 \\ 0 & -range & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} * M = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

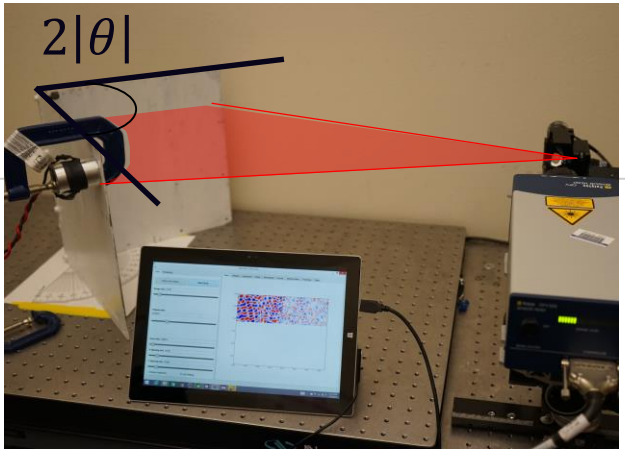
4 Interpolate at perspective projection coordinates within the original "skewed" scan

We can detect damage!



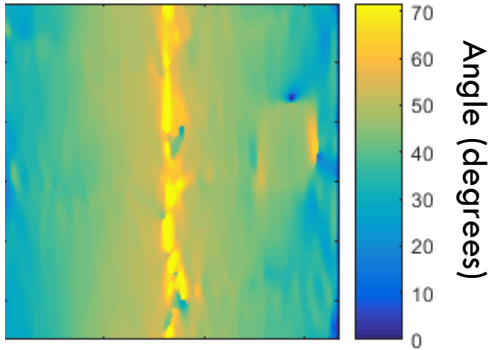
Damaged sample #3 scanned at 30° incidence angle

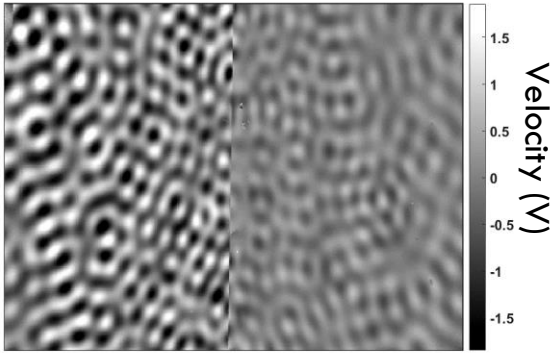
Incidence Angle from Wavenumber



- Algorithm can correct image based on “known” rotation angle
- Can detect incidence angle using changes in the nominal wavenumber response
  - Estimate the change in wavenumber at each pixel as compared to wavenumber at normal incidence angle

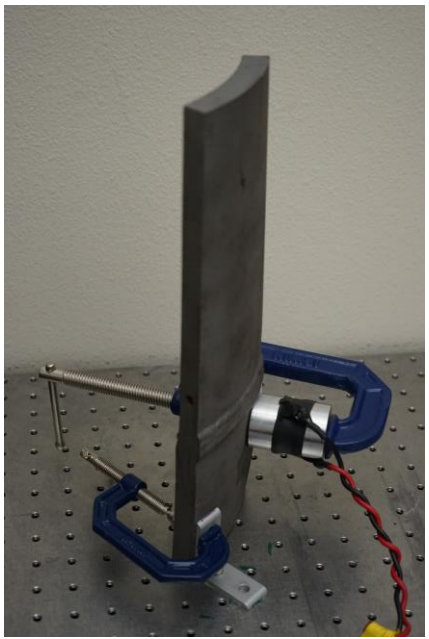
$$cos\theta = \frac{nominal\ wavenumber}{skewed\ wavenumber}$$

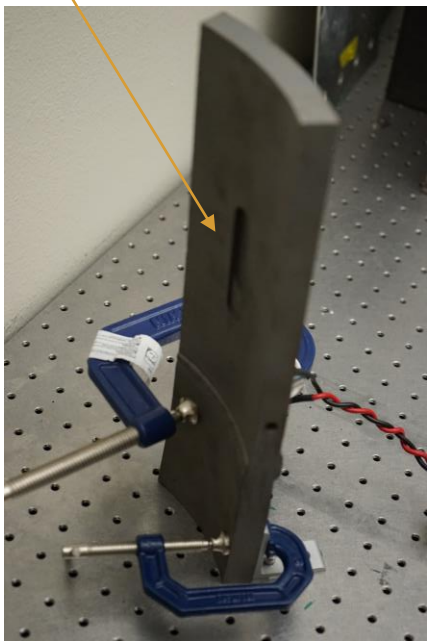




Future Investigations

- use 3D-range finder to by-pass first step of interpolation calculation- no longer need to define the 3D object
- use algorithm to “flatten” scans of cylindrical containers and other complex geometries



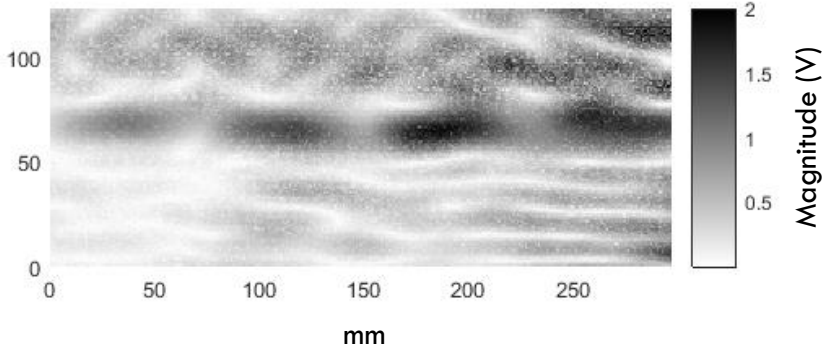


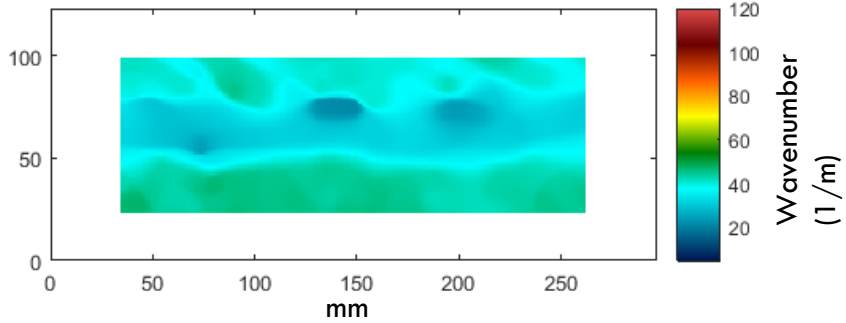
3

NDE of Composite Materials

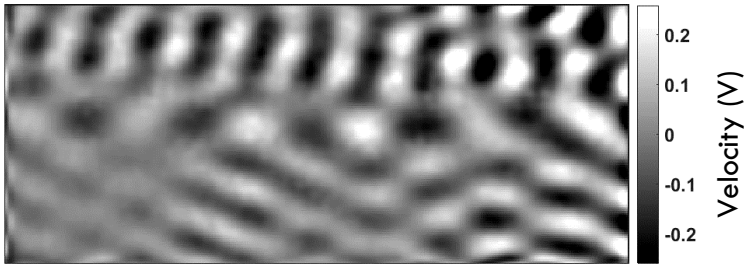
PW2- not damaged

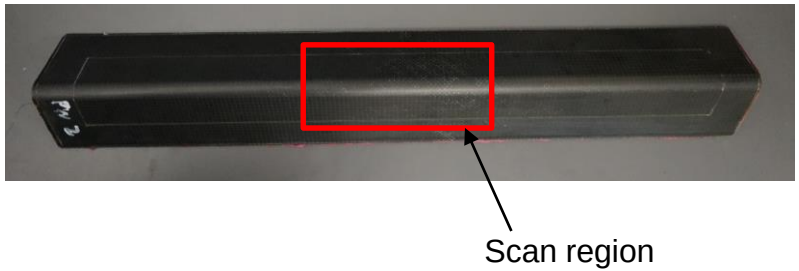
81.5 KHz excitation





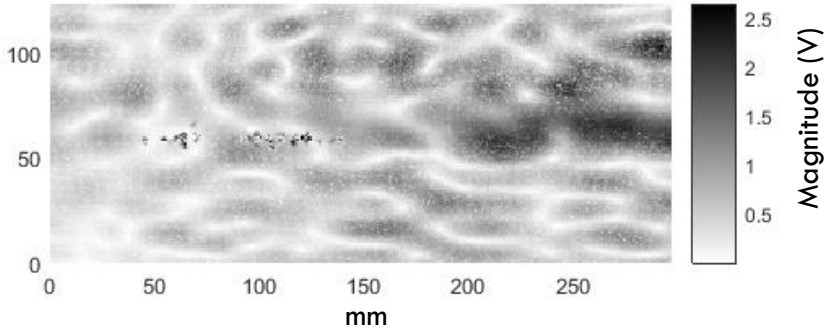
Animation/Video

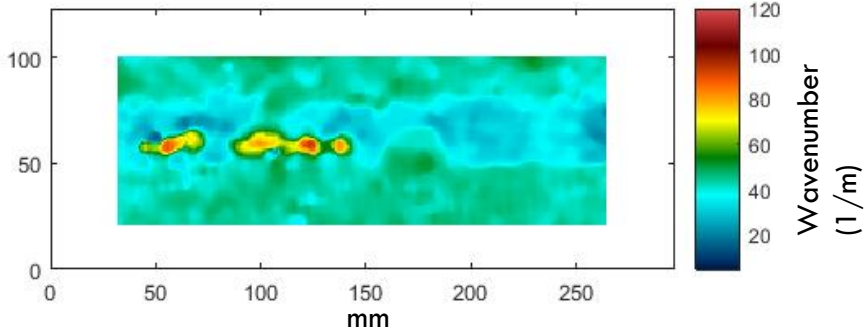




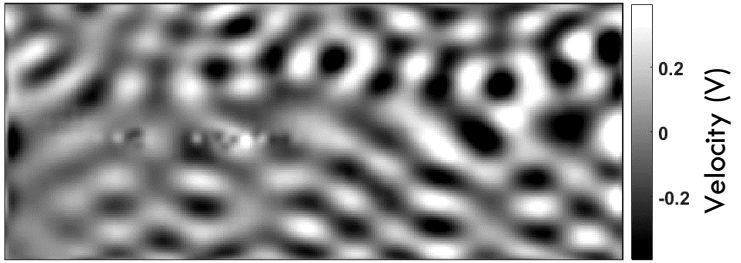
PW6- damaged

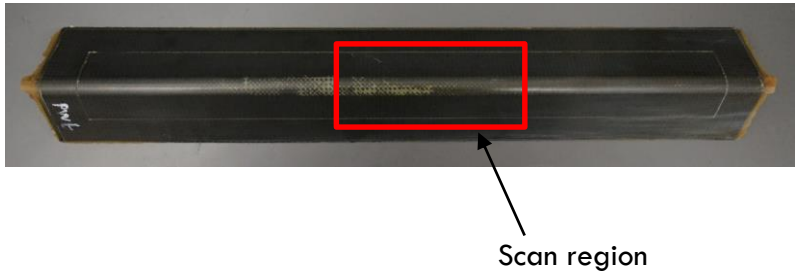
81.5 KHz excitation





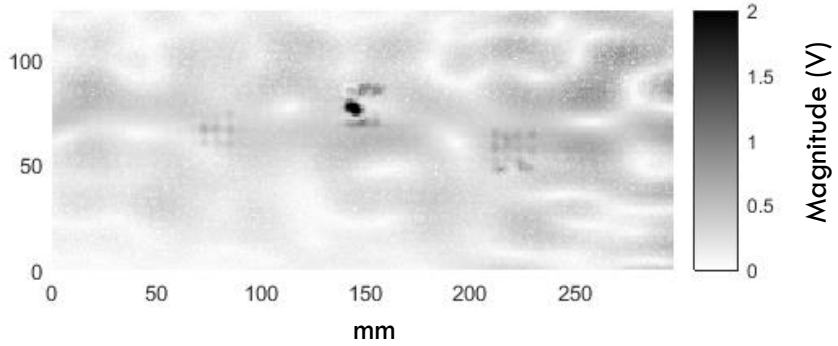
Animation/Video

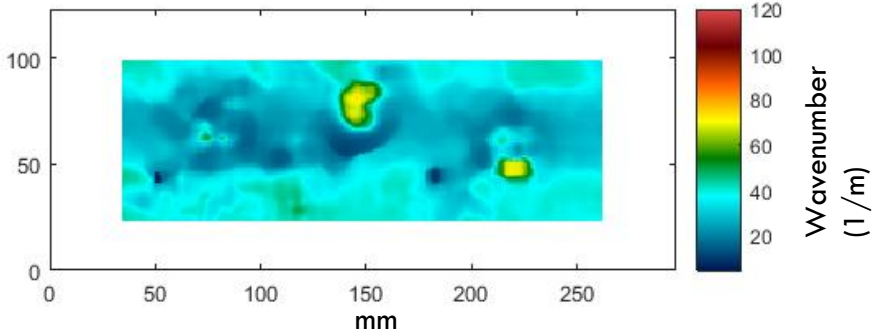




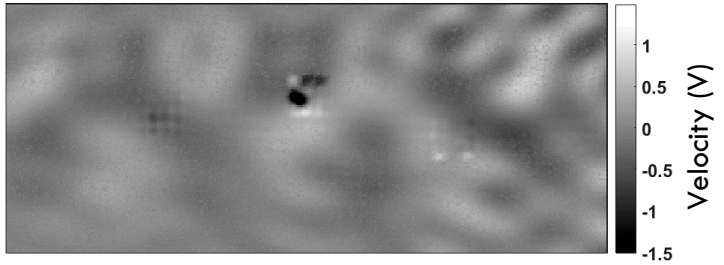
PW11- damaged

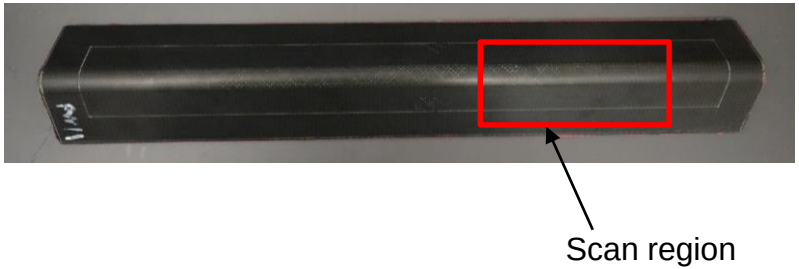
81.5 KHz excitation





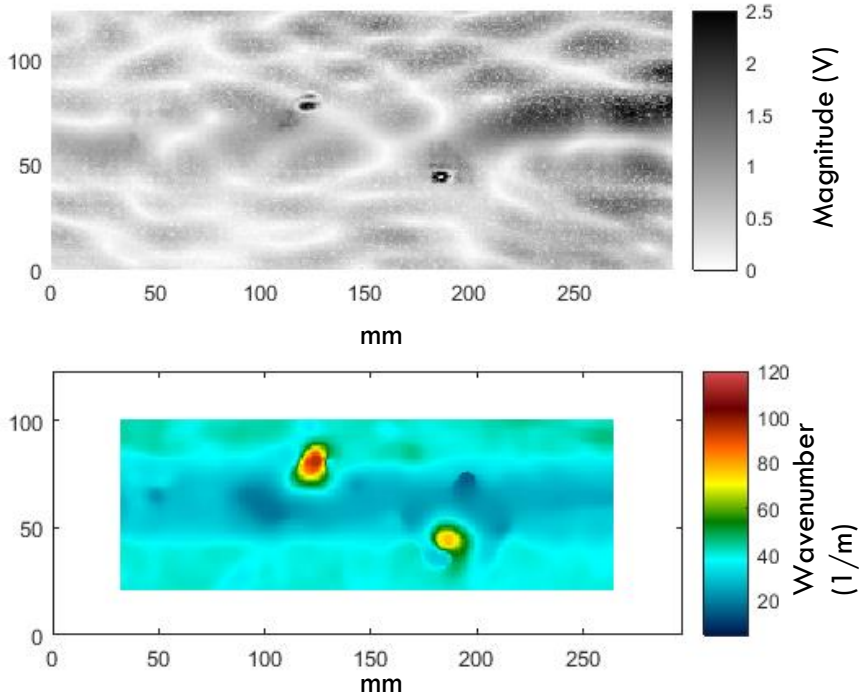
Animation/Video



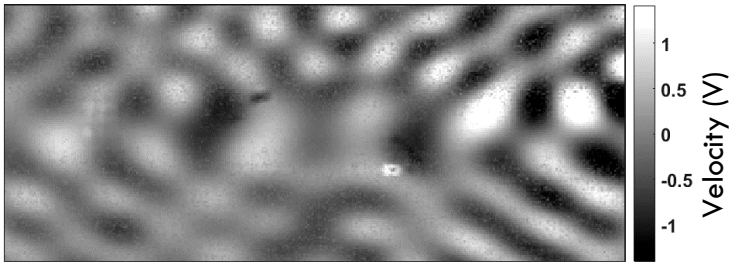


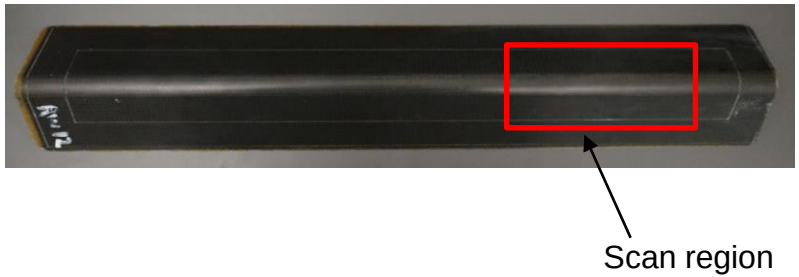
PW12- damaged

81.5 KHz excitation



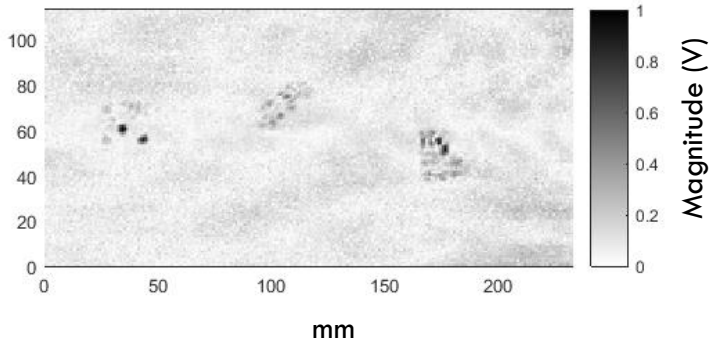
Animation/Video

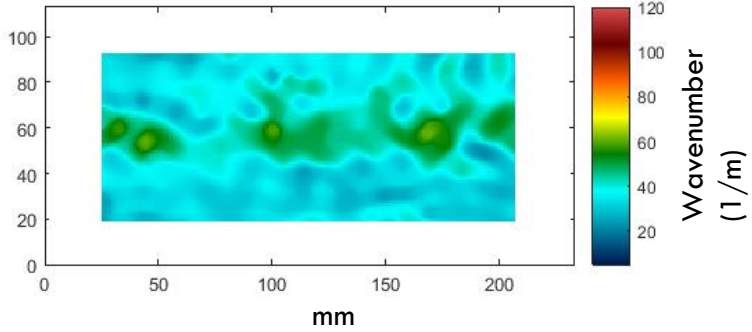




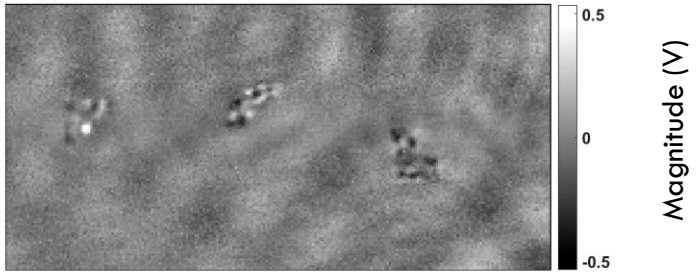
PW12- damaged

213 KHz excitation





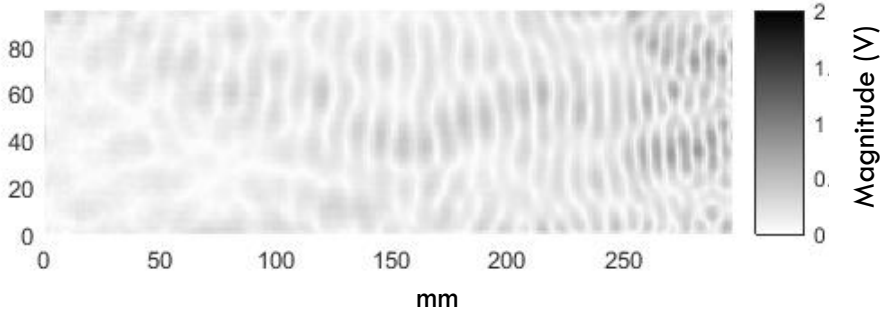
Animation/Video

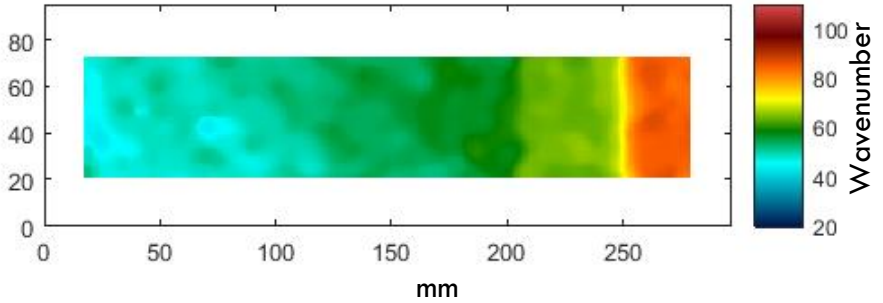


Smaller defects are more apparent with increasing excitation frequency. However, increasing excitation frequency results in a lower SNR.

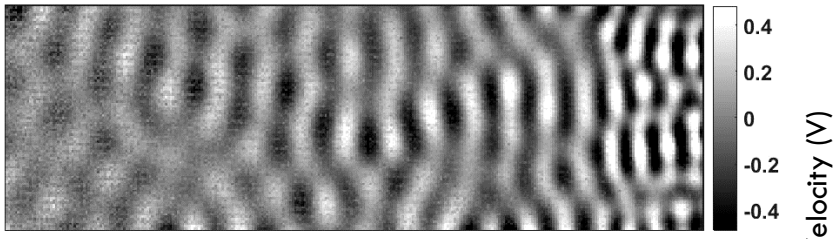
PWSW

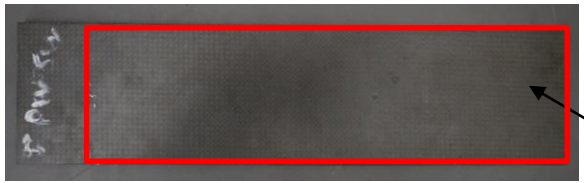
82 KHz excitation



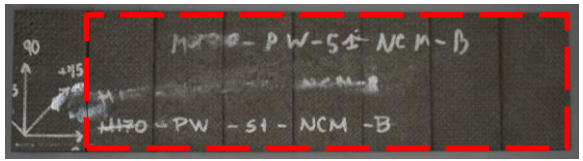


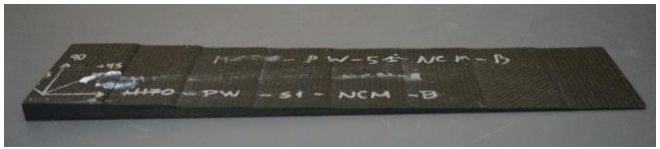
Animation/Video





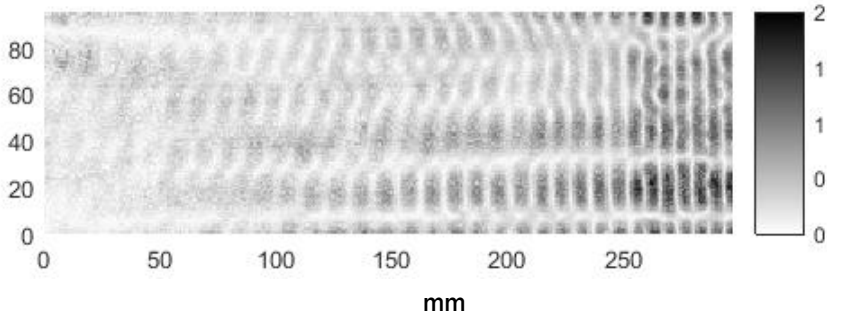
Scan region

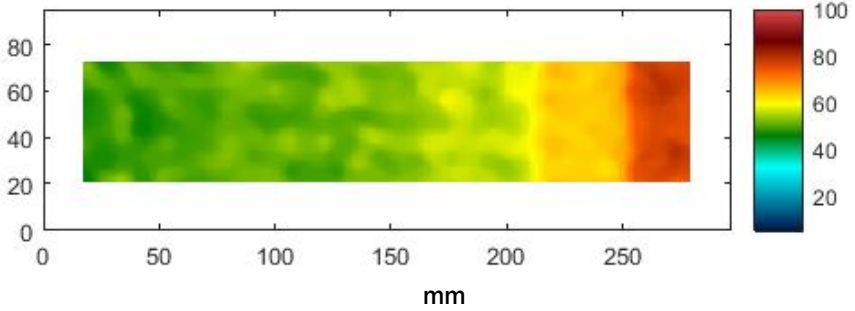




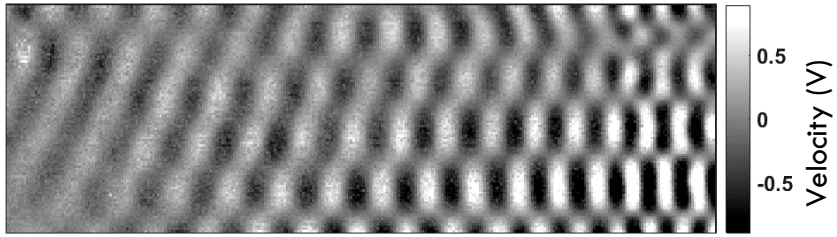
UDSW

81.5 KHz excitation

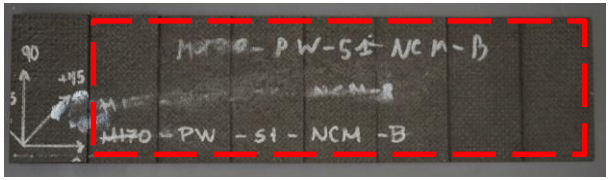


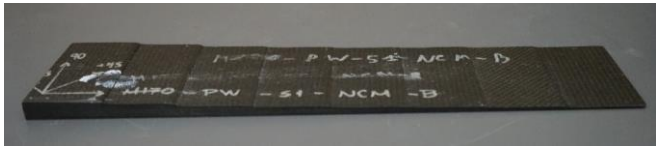


Animation/Video



Scan region





NDE Composite Research

Detect defects

We found both delimination and plastic radial inserts embedded within the composites.

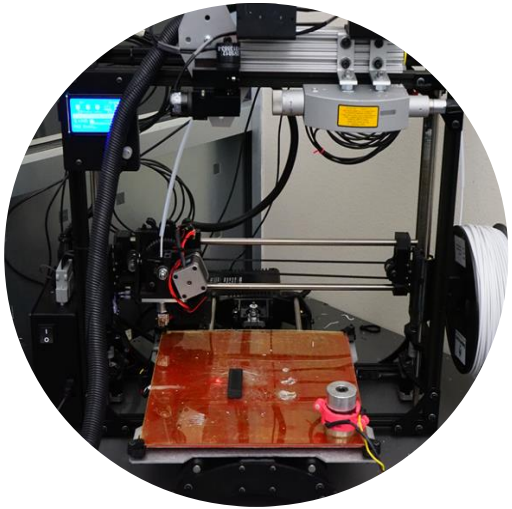
Detect changes in thickness

We were able to detect changes in thickness for two different composite materials.

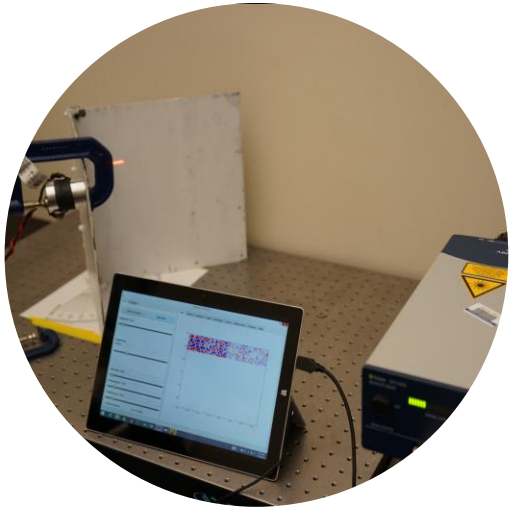
Balance trade-off of SNR and damage detection

In most of the scanned composites, a frequency of 134 KHz or higher was required to make defects “visible.”

Final Summary



Developed a **new in-situ technique** for the inspection of additively manufactured parts



Created an algorithm which can **correct "skewed" scans** of angular parts/taken at oblique angles

Used AWS to detect hidden defects and thickness changes in **aerospace composites**

Thanks for listening!

References

- Presentation template by SlidesCarnival
- Photograph by Royal Gazette