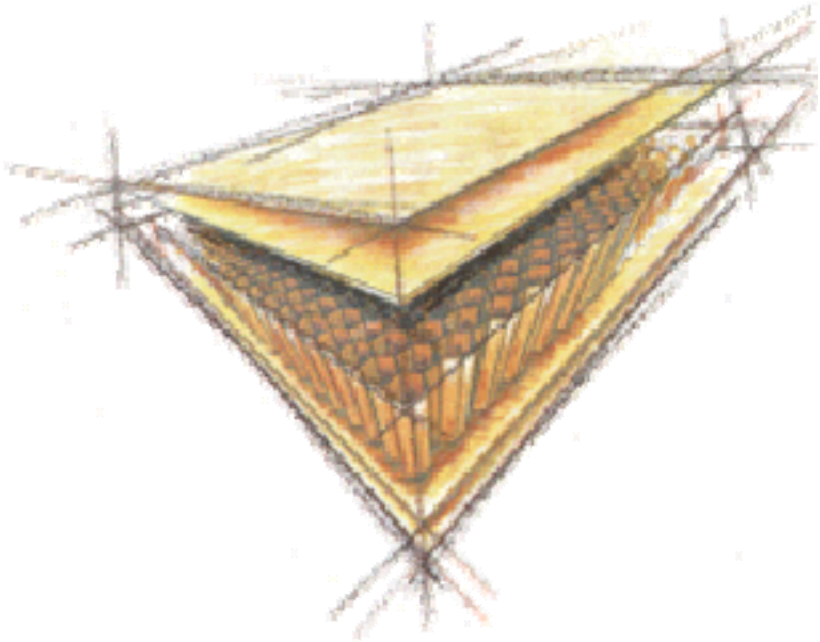
Active Piezoelectric Sensing for Damage Identification in Honeycomb Aluminum Panels

Andrew Swartz
Dan Backman
Eric Flynn

Advisors:
Jason Hundhausen
Gyuhae Park



Los Alamos Dynamics Summer School

Los Alamos National Laboratory

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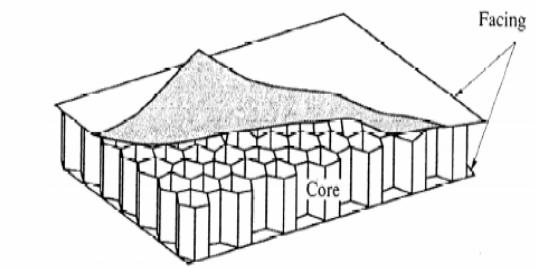
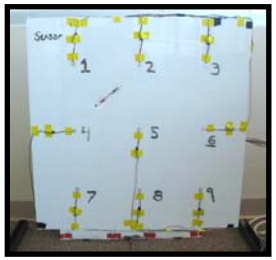
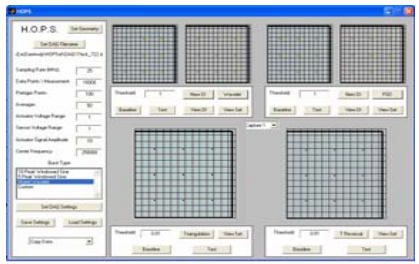
This presentation gives an overview of our Structural Health Monitoring research with honeycomb panels

Background & Theory

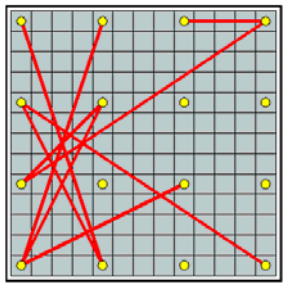


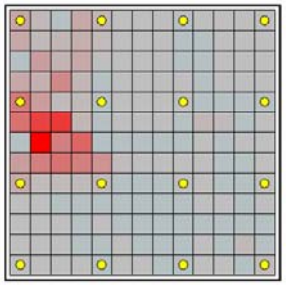
Experimental Procedure





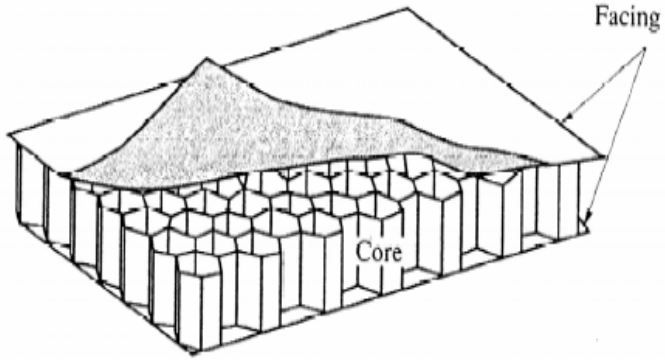
Results and Conclusions





Honeycomb panels offer a number of mechanical advantages useful in aerospace applications

www.mae.usu.edu

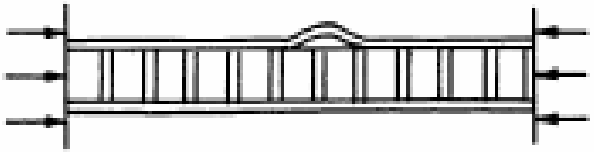


Whitehead et. al 2000

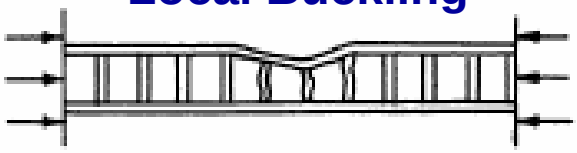
Health monitoring of these panels reduces the likelihood of catastrophic structural failure.

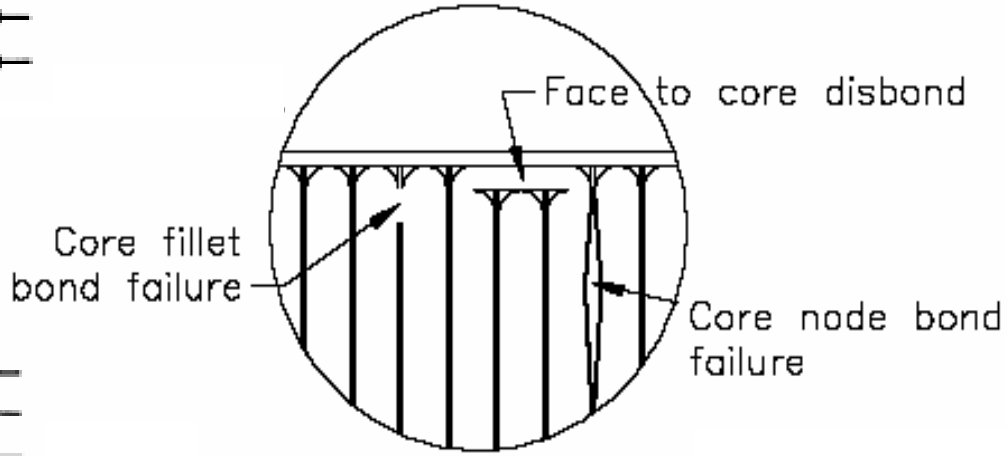
Our goal was to detect and locate damage in a honeycomb aluminum panel

Face Wrinkling



Local Buckling





Whitehead et. al 2000

We used piezoelectric based active sensing to detect damage

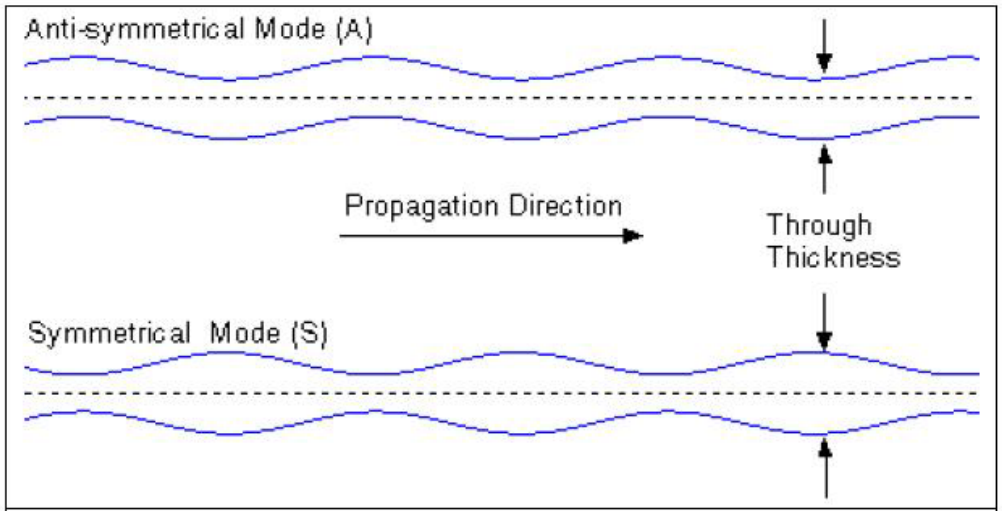
Our primary method of damage detection was through the use of Lamb wave propagation

Extractable Features

Attenuation

Reflection

Time of Arrival

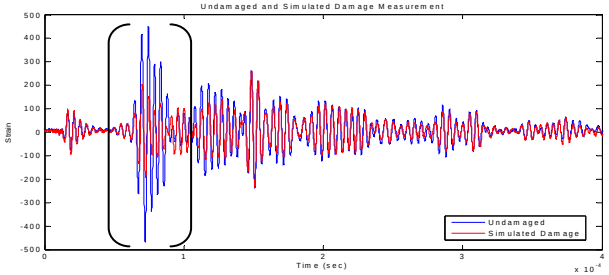


Kessler, et al. 2001

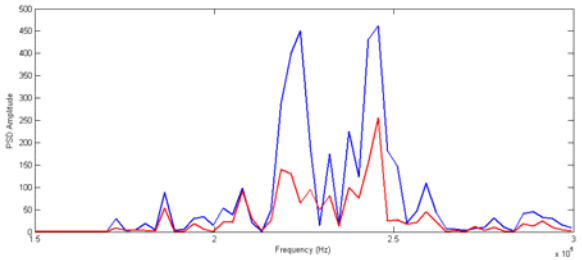
Lamb waves have wavelengths on the order of the thickness of the material

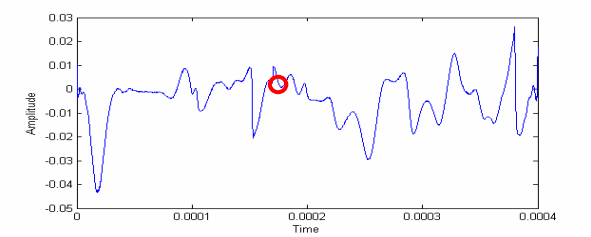
We employed four different methods for Lamb wave based damage detection

Wavelet Transform Integration

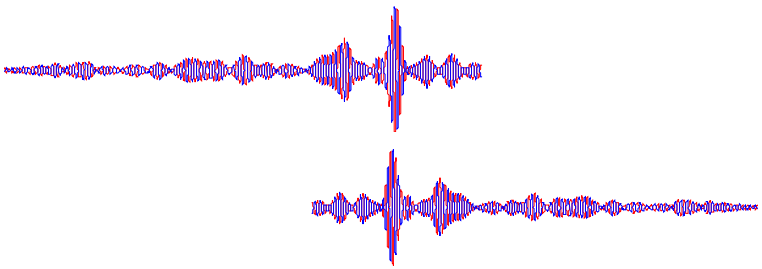


PSD Cross Correlation



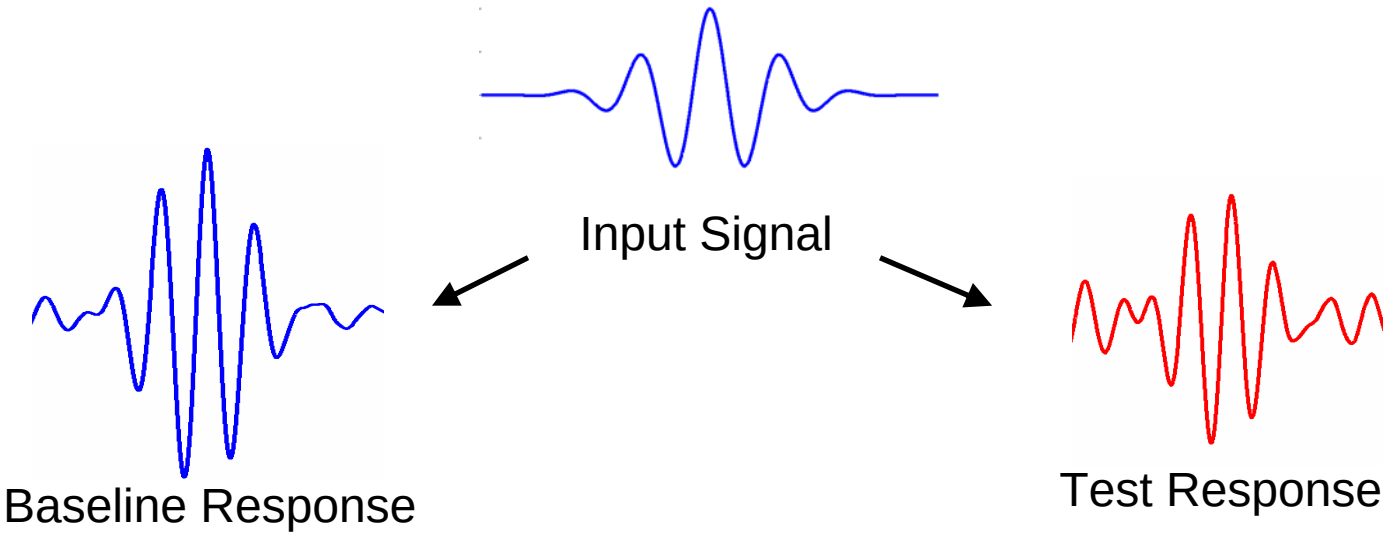


Wave Reflection Triangulation



Time Reversal

Wavelet Transform Integration



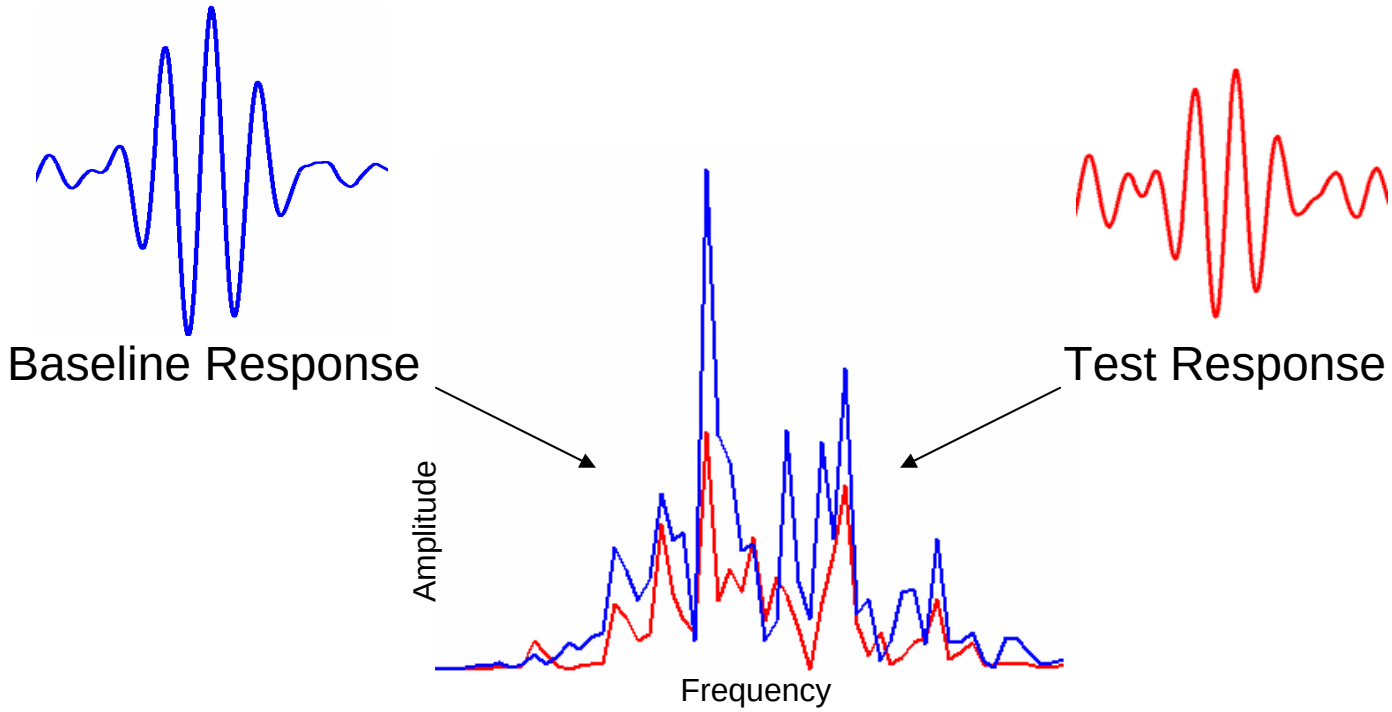
Wavelet Transform — Translation — Input Dilation

$$Feature = \int_{u_0}^{u_1} Wf(u, s_0)du$$

Sohn, et al. 2003

$$DamageIndex = \left| \frac{BaselineFeature - TestFeature}{BaselineFeature} \right|$$

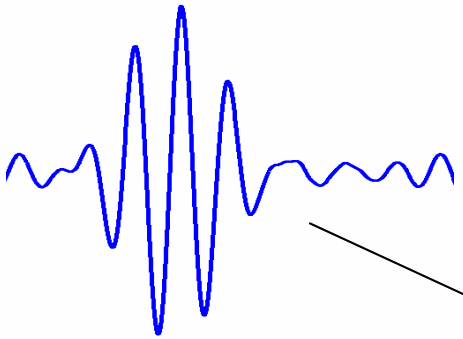
Power Spectral Density Cross Correlation



Maximum Cross Correlation Baseline PSD Test PSD

$$DamageIndex = r_{Gyy_B Gyy_T}$$

Wave Reflection Triangulation

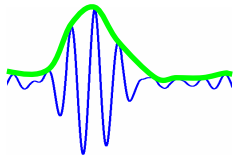


Baseline Response

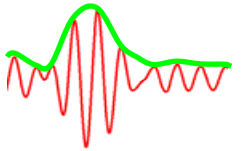
Hilbert Transform

$$\{Hs\}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{s(\tau)}{t-\tau}d\tau$$

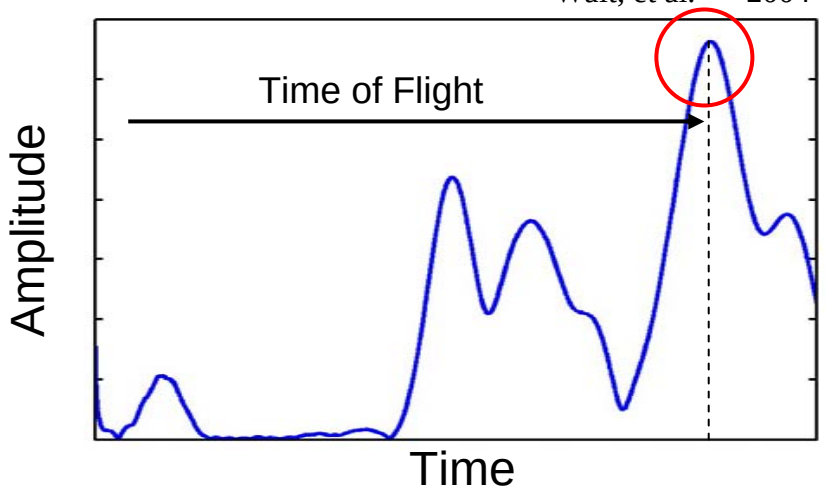
Test Response



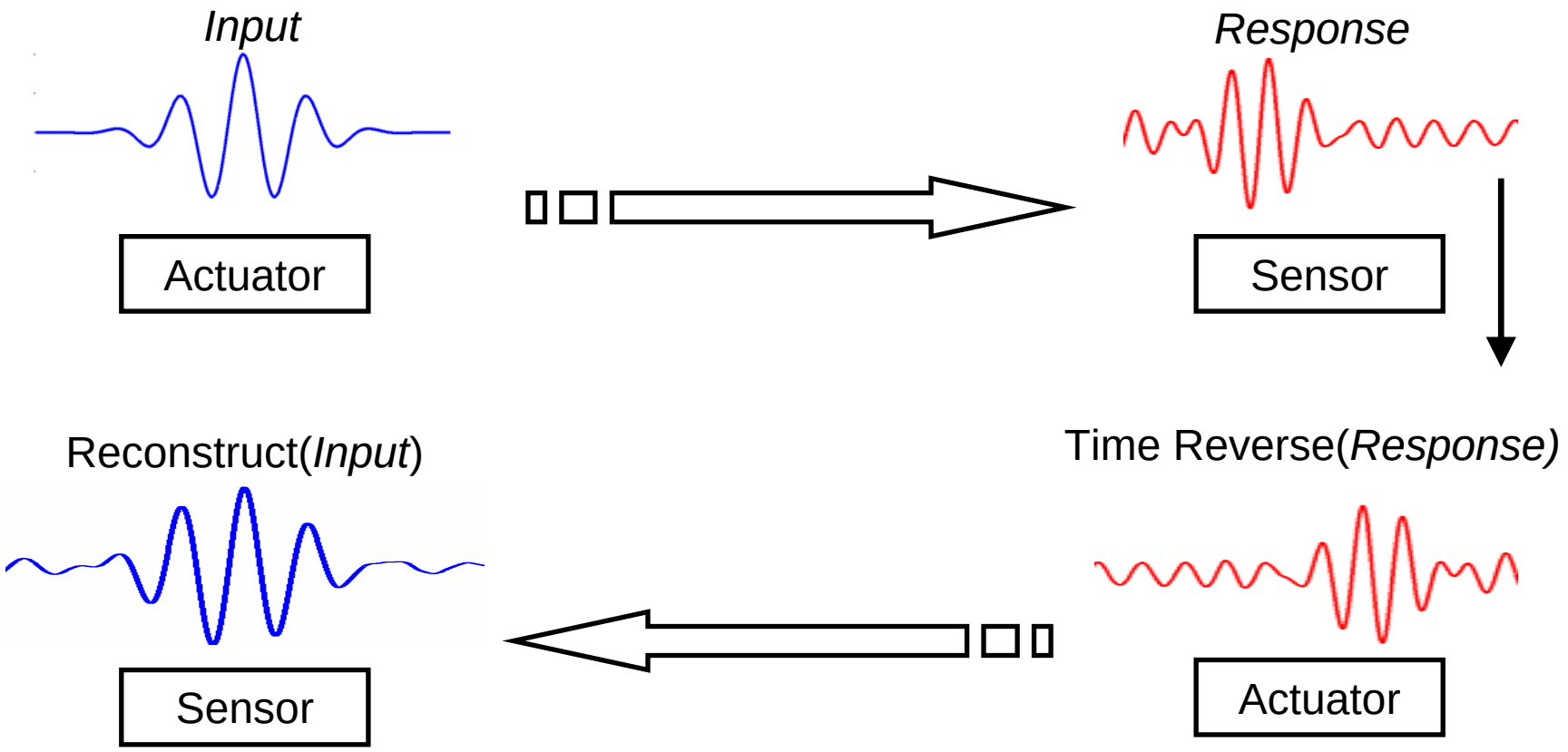
$$\|\{Hs\}(t)_{Test}\| - \|\{Hs\}(t)_{Baseline}\|$$



Wait, et al. 2004

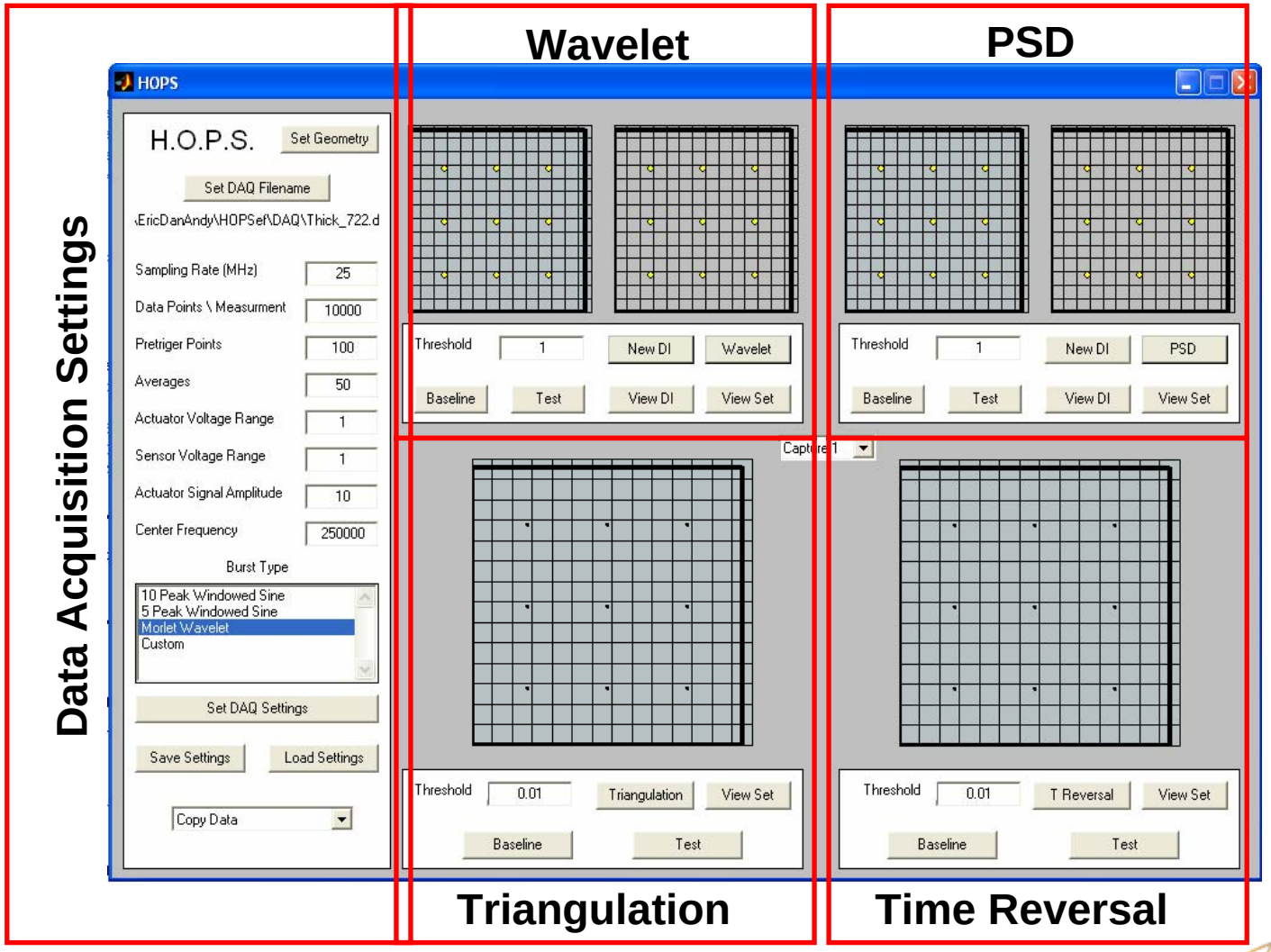


Time Reversal Acoustics



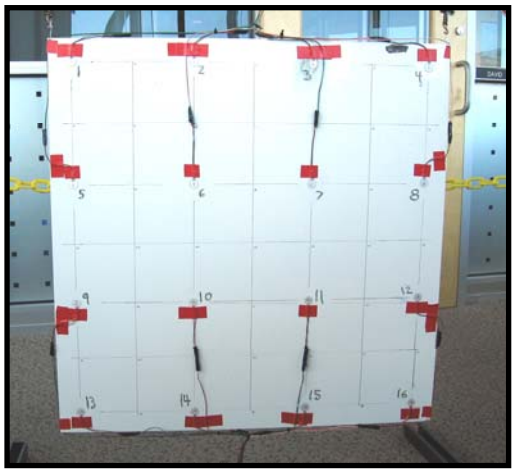
$$DamageIndex = \int \left(\text{Reconstruct}\left(Input\right) + \text{Reconstruct}\left(-Input\right)\right)dt$$

Health Of Plate Structures (H.O.P.S.) was developed to merge the various analysis methods



We instrumented two honeycomb panels of different thicknesses with arrays of PZT patches

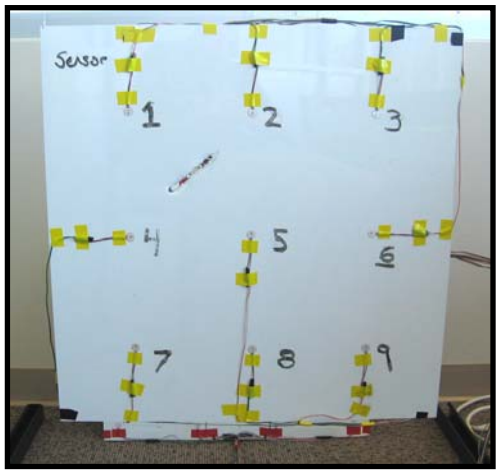
61cm x 61cm x 6mm



4 x 4 PZT Grid

Free-Free Support

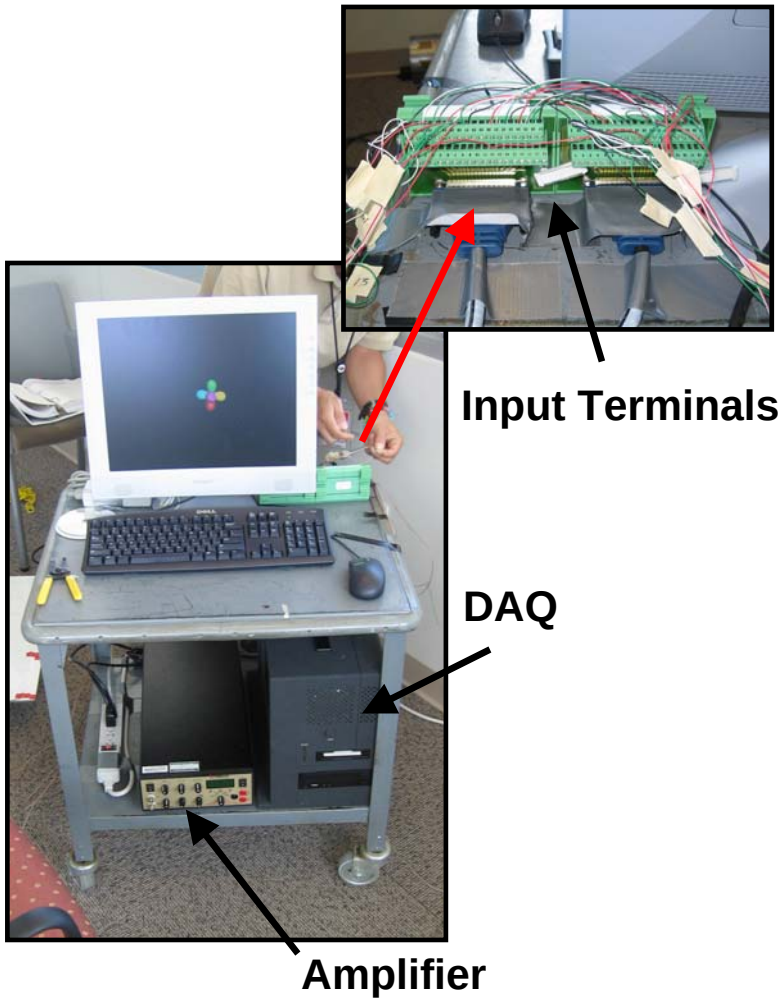
61cm x 61cm x 13mm



3 x 3 PZT Grid

Patches attached using standard super glue

Data were acquired using a commercially available data acquisition system

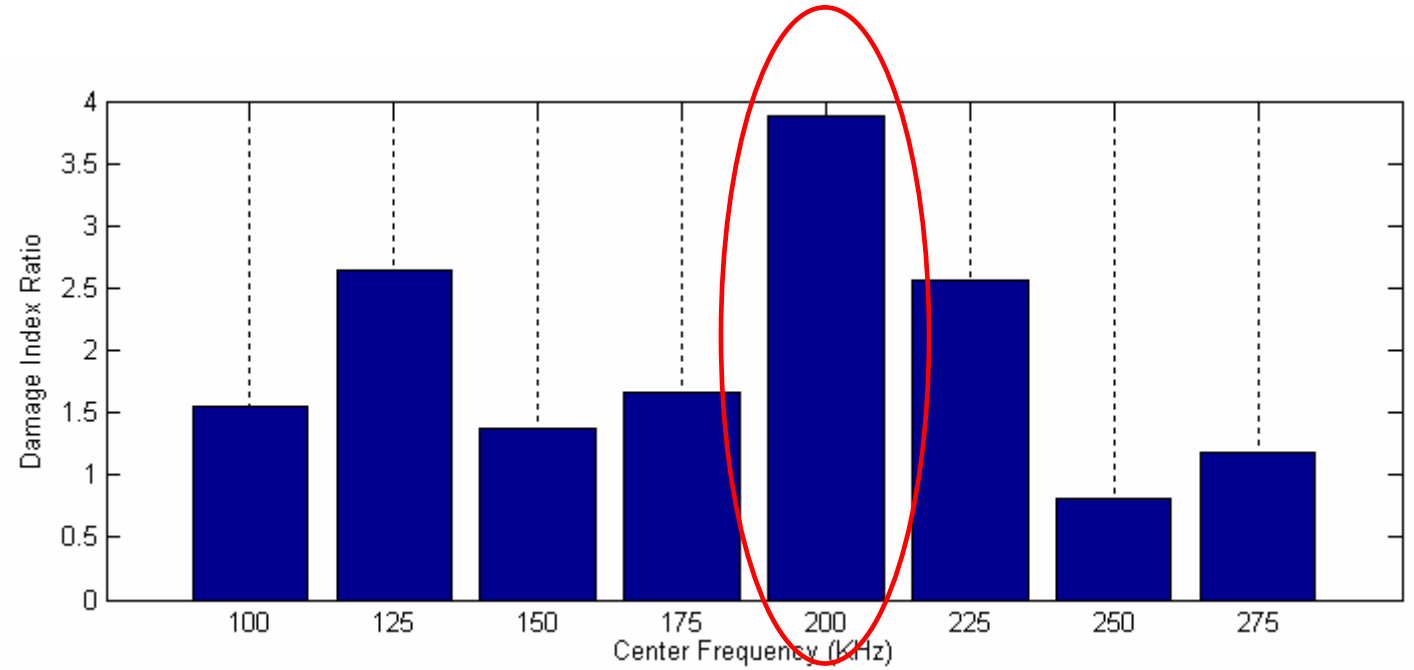


Each PZT was wired as both an actuator and sensor

Signals were multiplexed to one actuator and one sensor

Data acquired at a 25 MHz sampling rate

Due to model complexity, optimal Lamb wave center frequencies had to be determined experimentally



6 mm : 200 KHz

13mm: 250 KHz

$$Damage\ Index\ Ratio = \frac{Mean\left(Damage\ Indices\ of\ \ Damaged\ \ Paths\right)}{Mean\left(Damage\ Indices\ of\ Undamaged\ \ Paths\right)}$$

Experimental Procedure

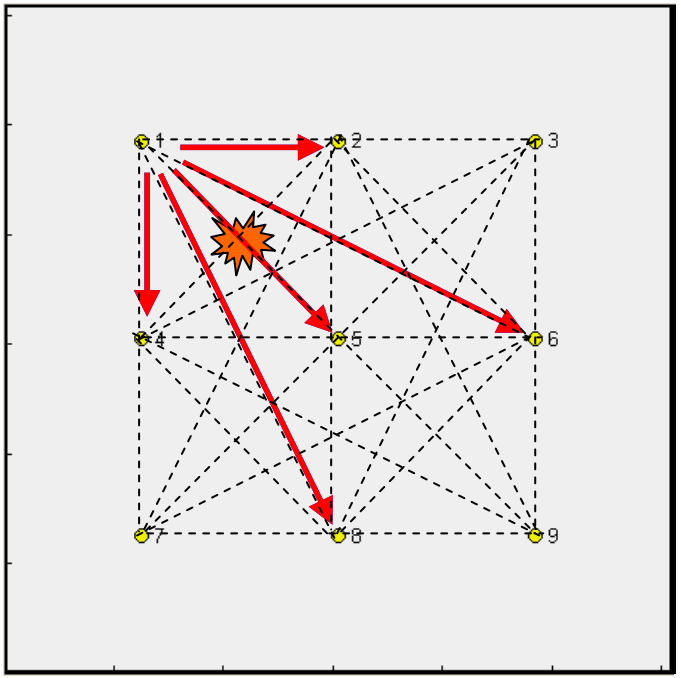
Assign actuator-sensor paths

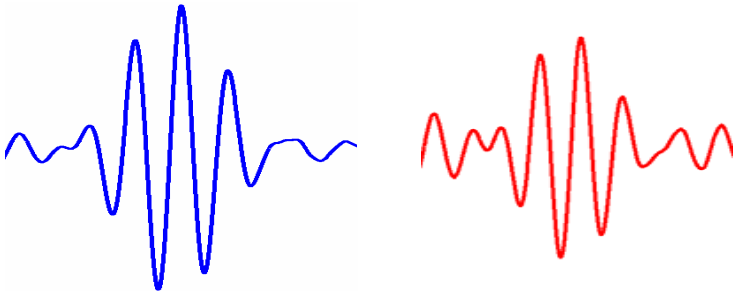
Propagate Lamb wave from actuators to sensors to acquire baseline responses

Apply damage (simulated or real)

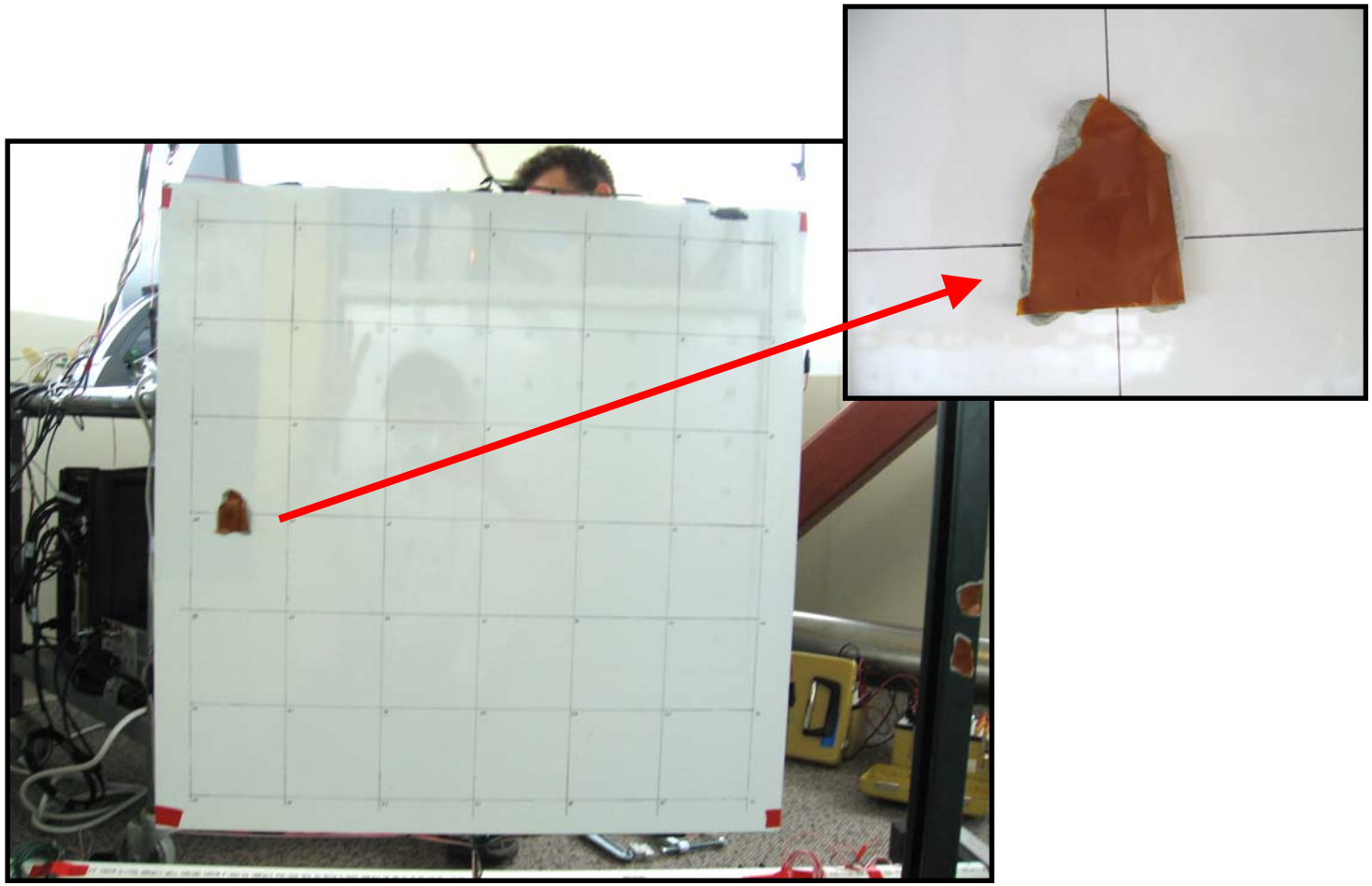
Acquire test responses

Apply signal processing techniques



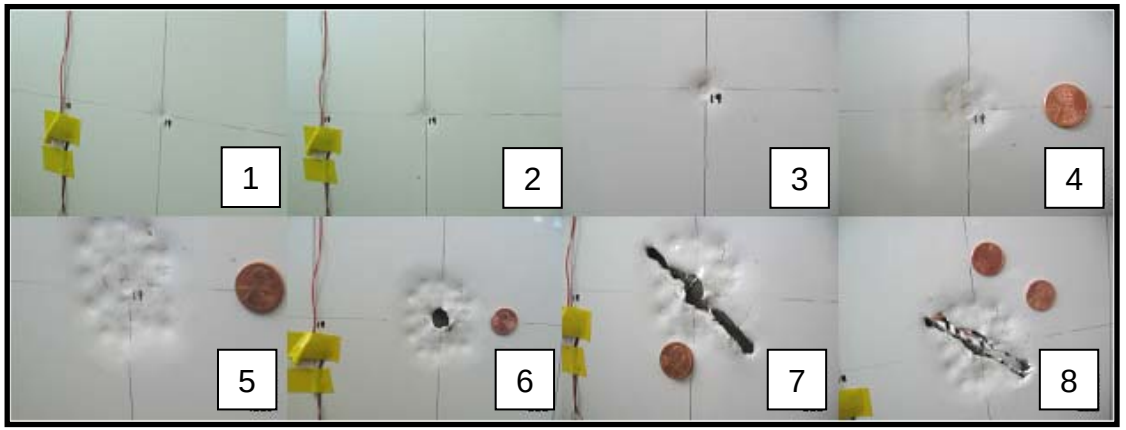


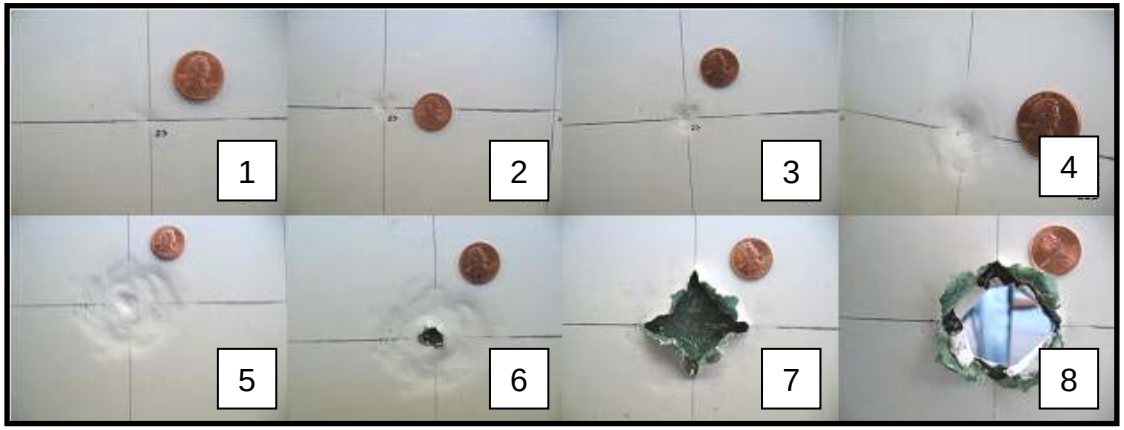
We first simulated damage by sticking industrial putty to honeycomb facing



We then progressively added real damage by applying localized pressure to the *rear* facing

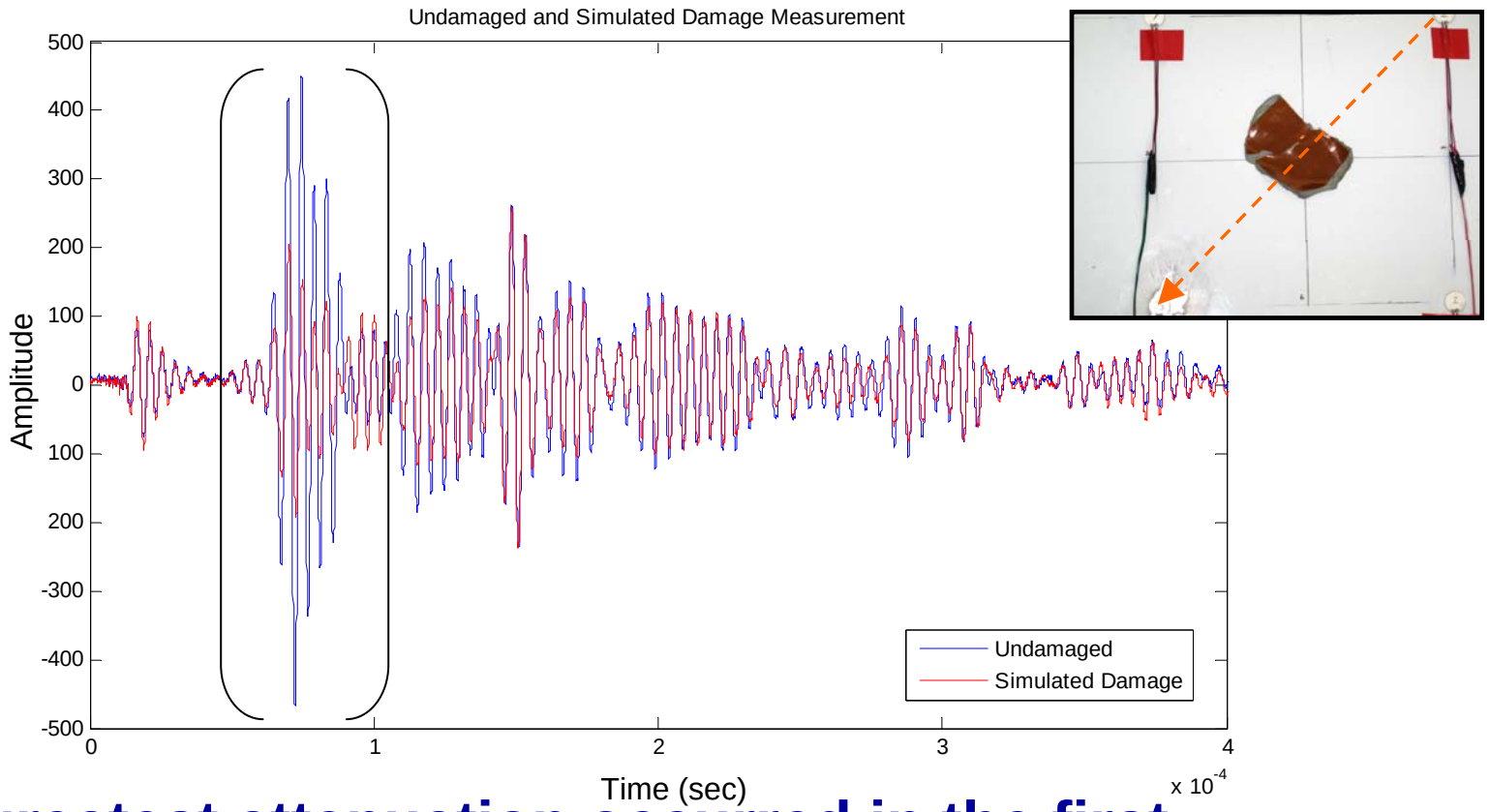
13 mm Plate





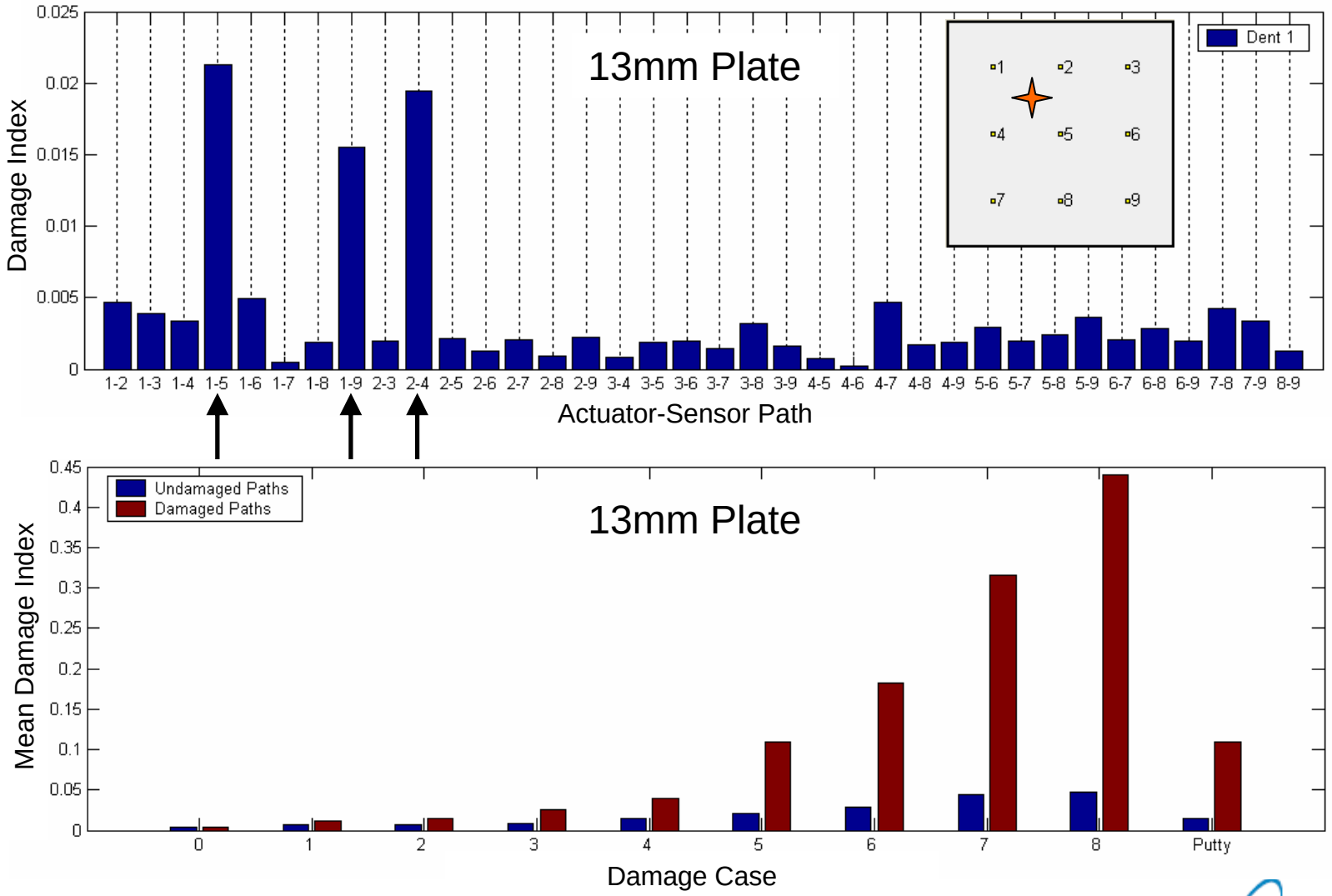
6 mm Plate

Visible levels of Lamb wave attenuation were observed as a result of adding simulated damage

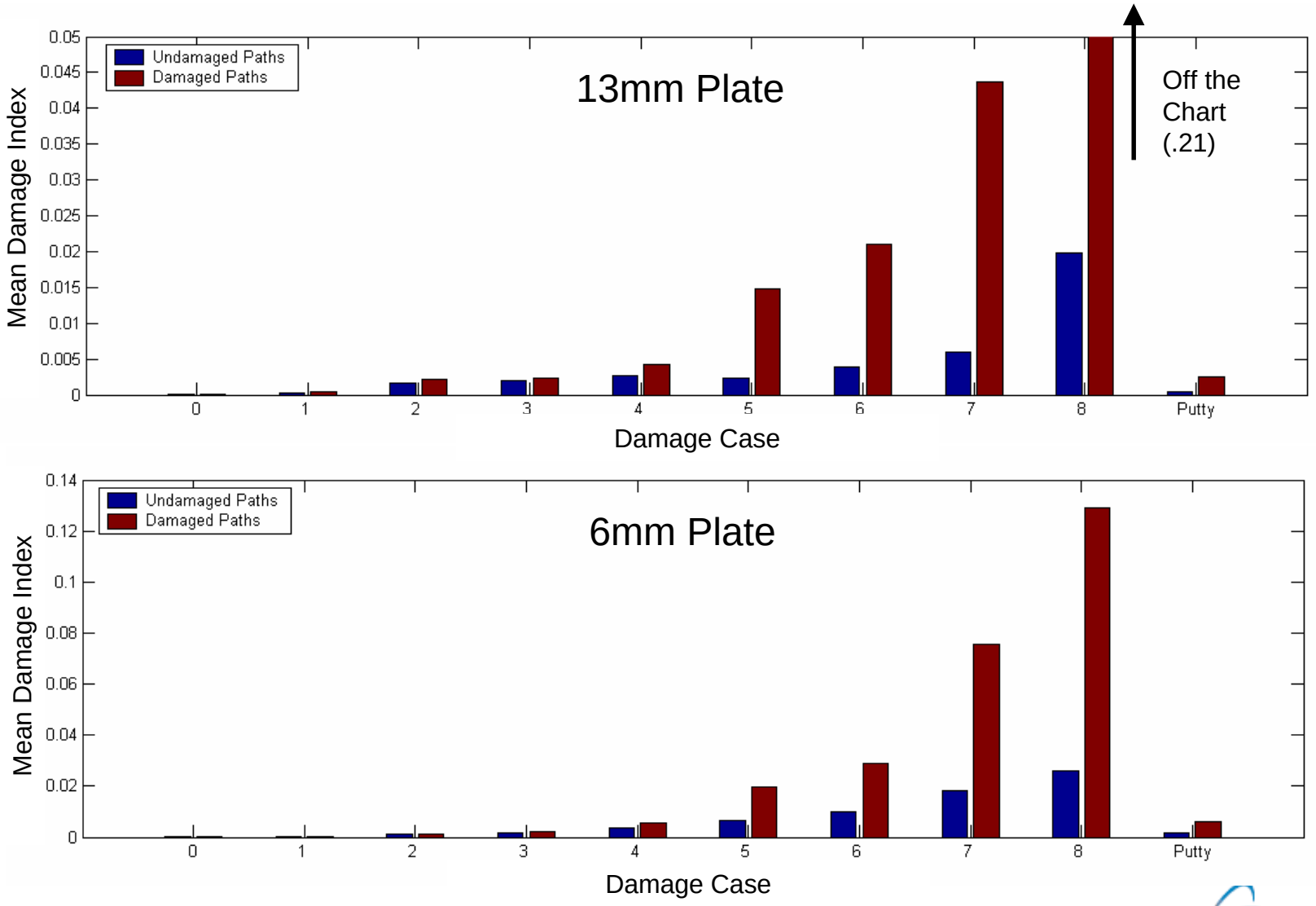


The greatest attenuation occurred in the first-arrival symmetric mode

Damage Index Results - Wavelet Transform

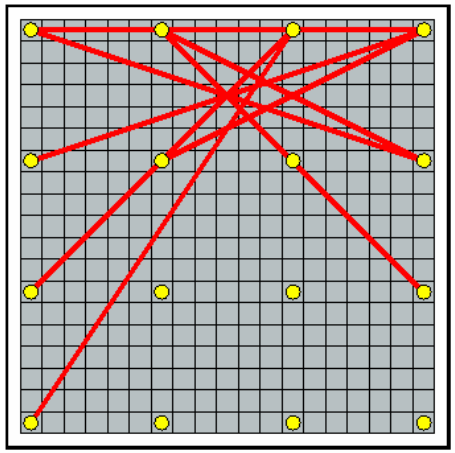


Damage Index Results – PSD Cross Correlation



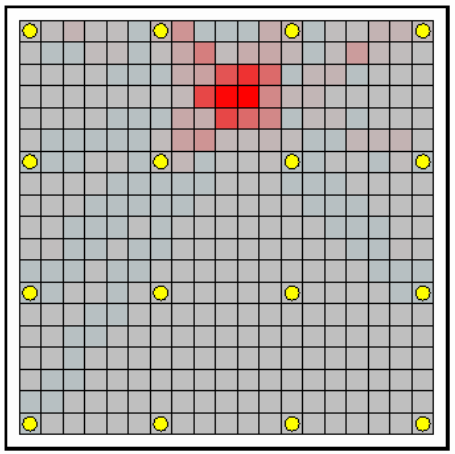
After calculating a damage index for each path, we determined the damage location

Find all paths > Damage Threshold



Form grid of boxes

Box damage = $\frac{\text{\# of damage crossings}}{\text{total \# of paths}}$

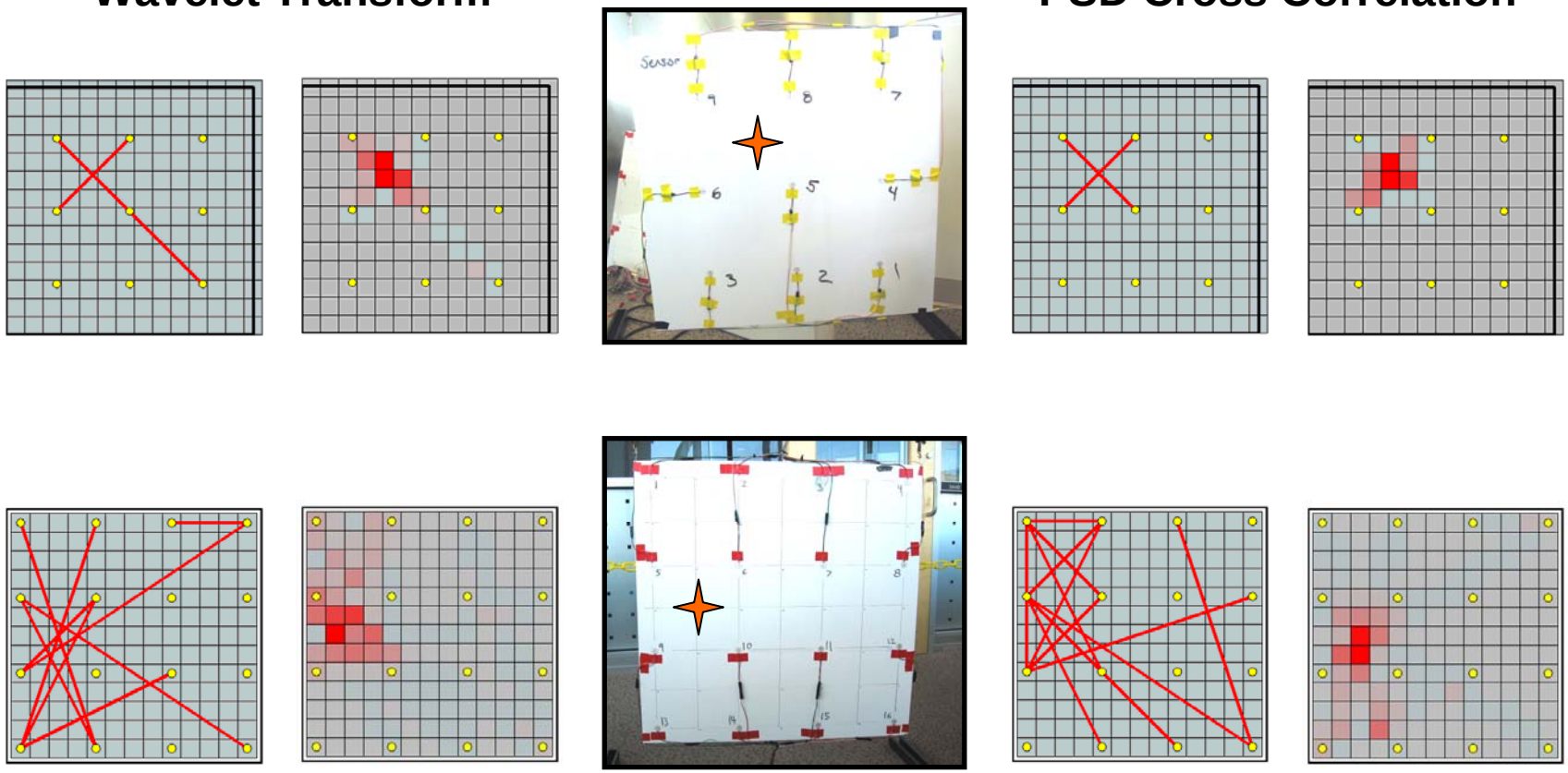


Indicate box damage with red shading

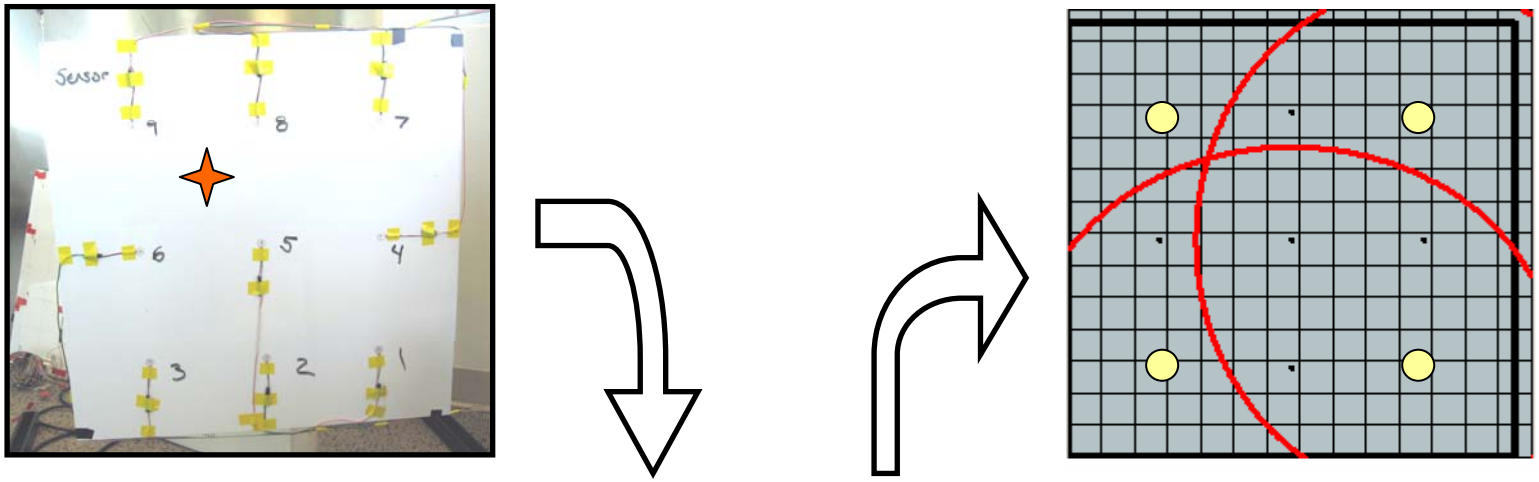
Damage Localization for Wavelet Transform and PSD Cross Correlation Methods

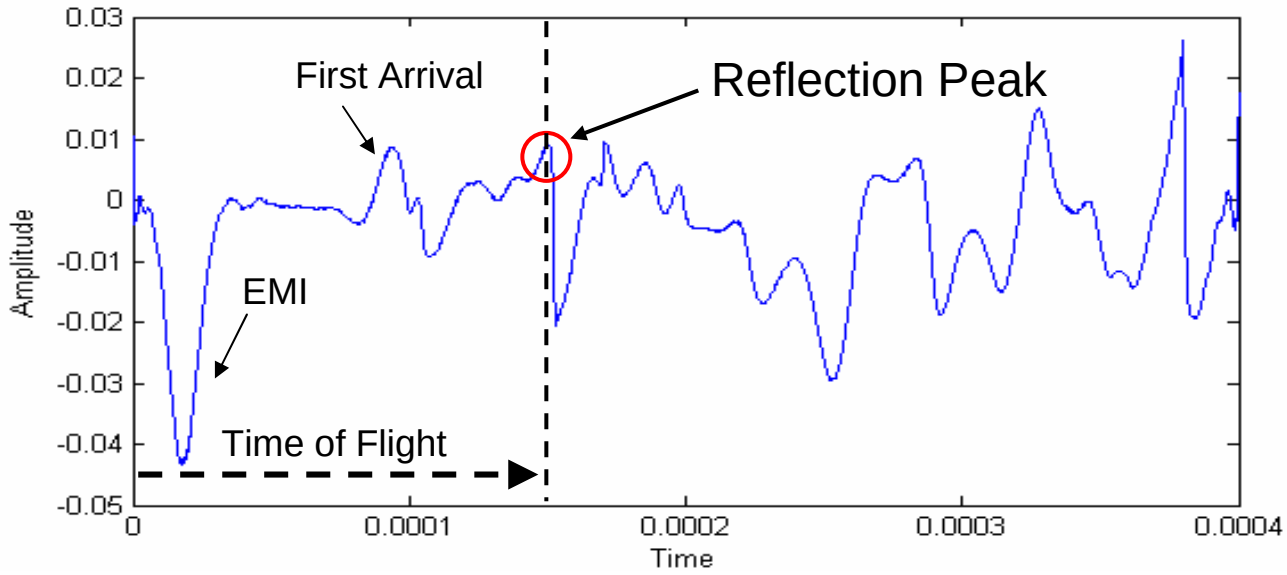
Wavelet Transform

PSD Cross Correlation



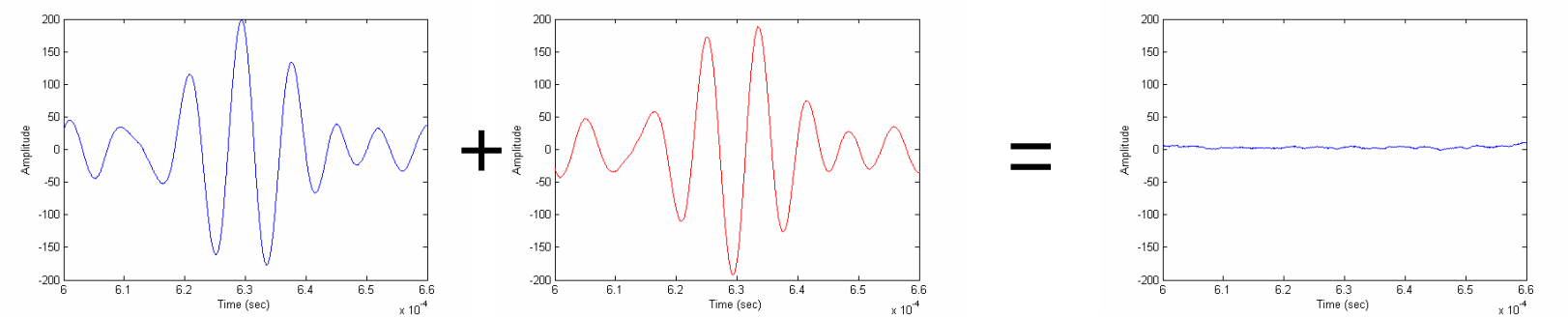
Wave Reflection Triangulation Results



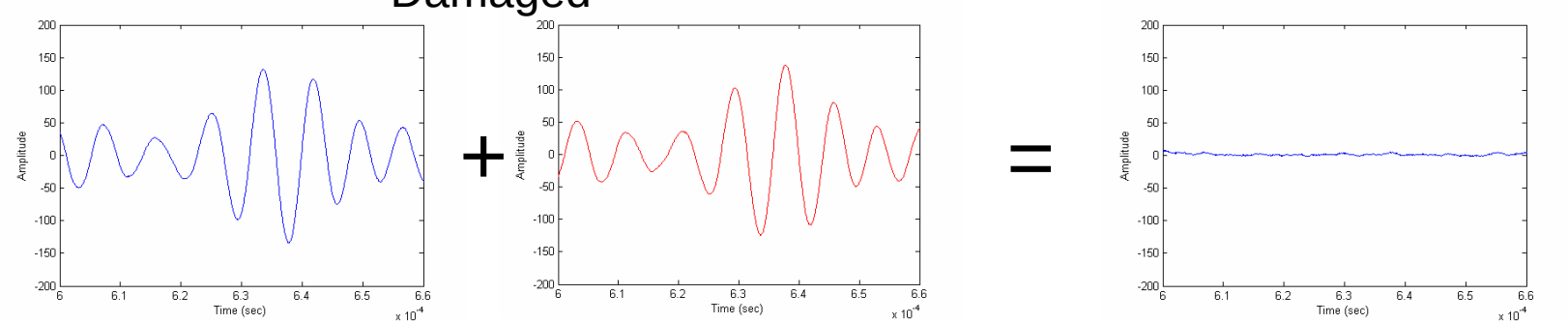


Time Reversal methods were unable to detect damage due to linearity of damage

Undamaged



Damaged

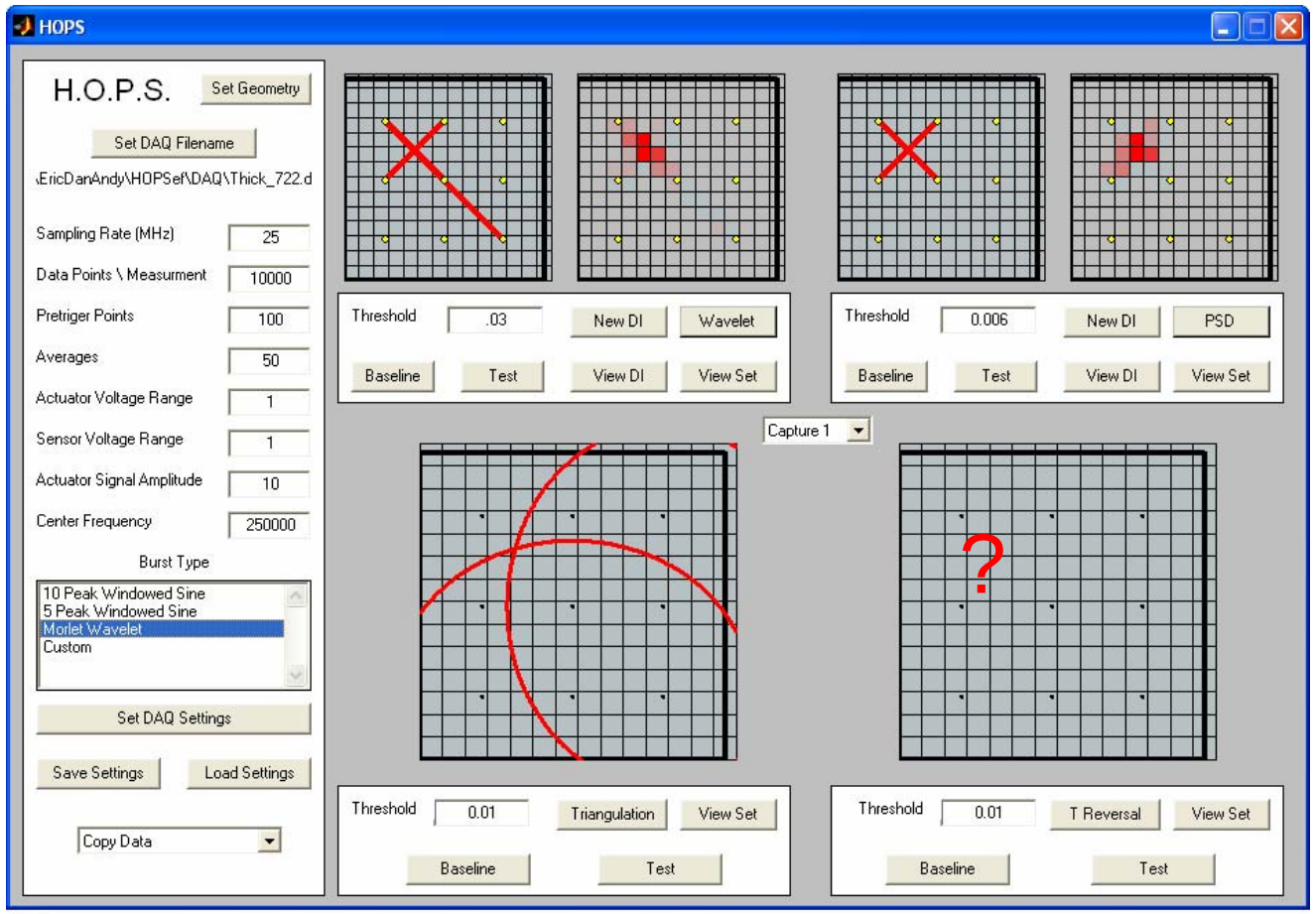


Time reversal methods with baseline measurements have the potential for increased sensitivity at the expense of acquisition time

The various analysis techniques compliment each other when combined as one tool

Wavelet PSD

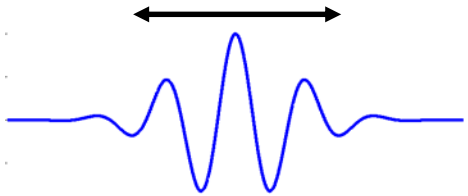
Data Acquisition Settings



Triangulation Time Reversal

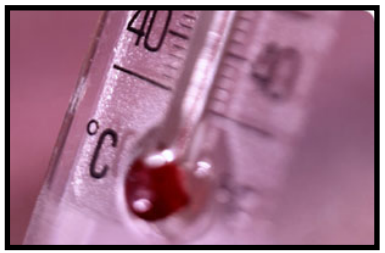
Future Work

More thorough investigation of optimal Lamb wave frequency

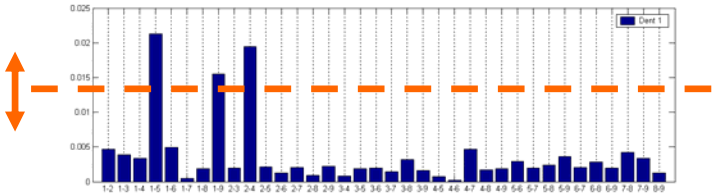


Further investigation into time-reversal methods

Determining and compensating for environmental factors



Incorporation of statistical analysis for determining proper damage threshold levels



Acknowledgements

LANL Engineering Sciences and Applications Division

Mathworks

ABAQUS

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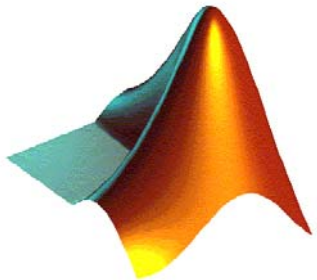
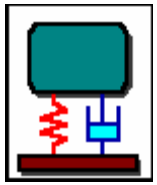
Mr. Scot Hart





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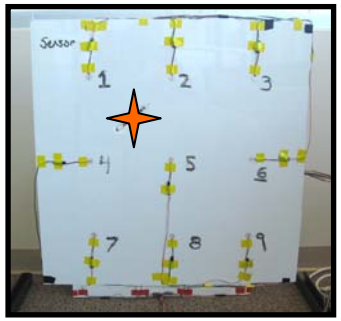
Summary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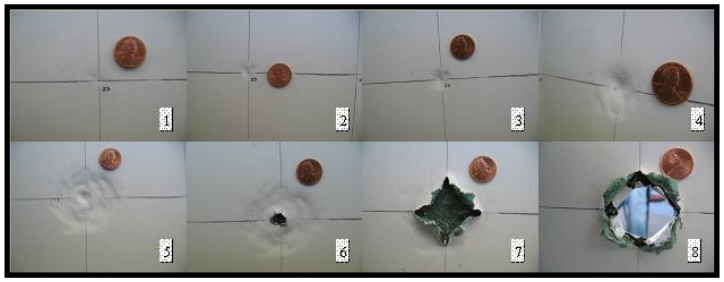
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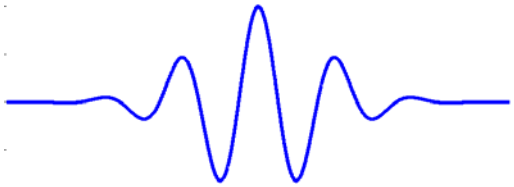

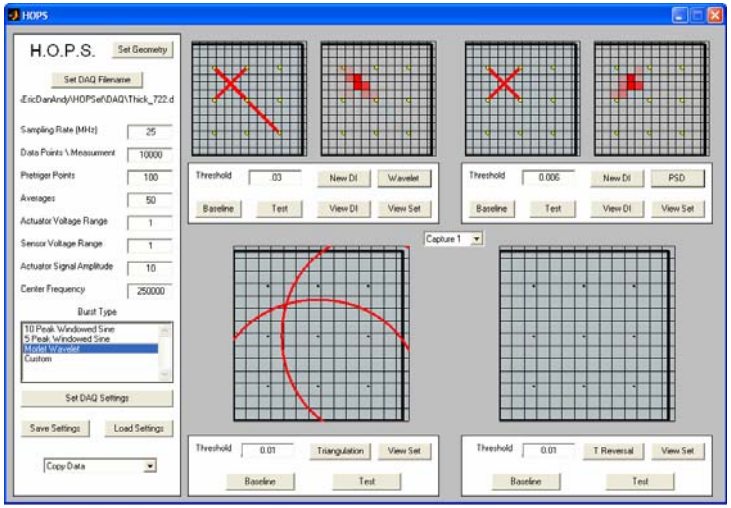
HOPS
H.O.P.S.
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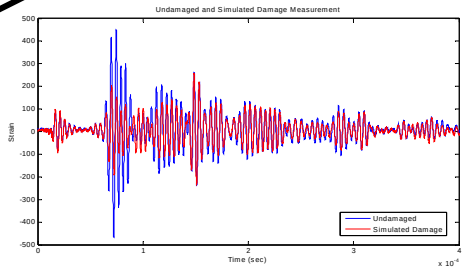
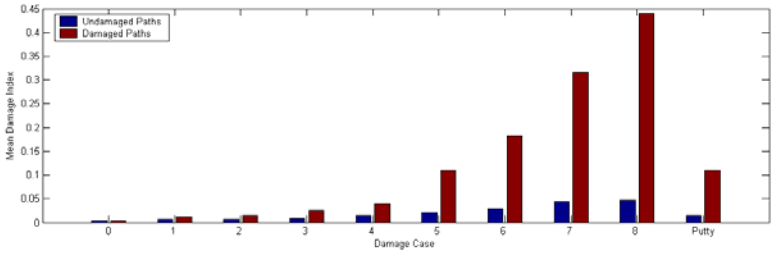
Set DAQ Filename
Sampling Rate (MHz)
Data Points \ Measurement
Pretrigger Points
Averages
Actuator Voltage Range
Sensor Voltage Range
Actuator Signal Amplitude
Center Frequency
Burst Type
Set DAQ Settings
Save Settings
Load Settings
Copy Data
Threshold
New DI
Wavelet
PSD
Baseline
Test
View DI
View Set
Capture 1
Triangulation
T Reversal


Undamaged and Simulated Damage Measurement
Strain
Time (sec)
Undamaged
Simulated Damage


Undamaged Paths
Damaged Paths
Mean Damage Index
Damage Case
Putty