Damage Detection in Carbon Fiber Composite Materials Using Lamb Waves: FFT vs. PCA

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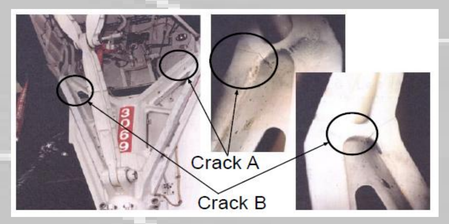
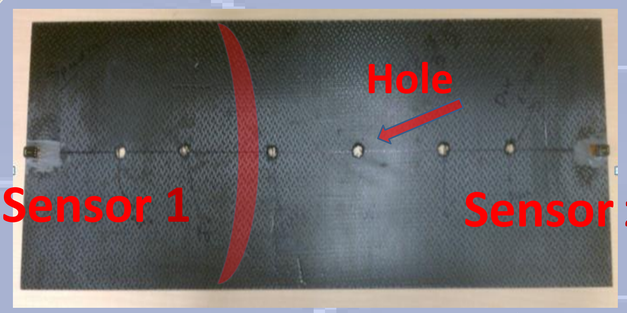
STATUS QUO



Chang (2011) Lecture Notes

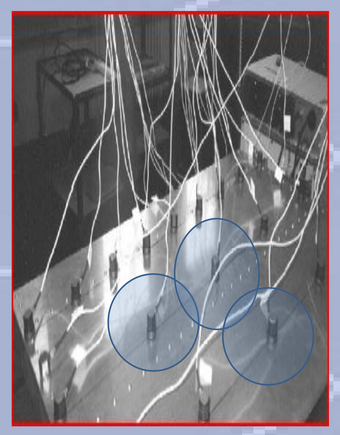
Piezoelectric sensors produce Lamb waves that can be used to identify damages at a lower cost in the increasingly common carbon fiber composites.

EXPERIMENT



Carbon Fiber Composite Board

Piezoelectric Sensor



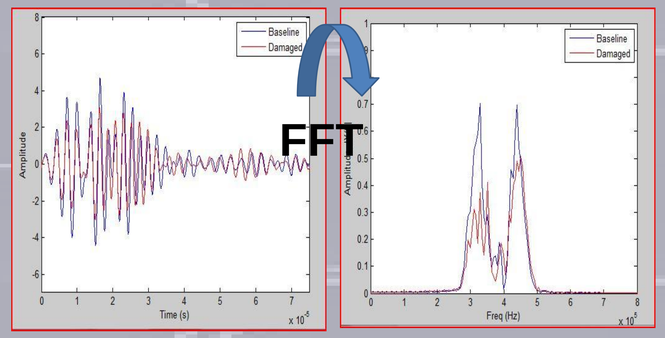
Sensors on airplane wing

- 10 x 27 in. carbon fiber composite plate
- Damages were introduced at varying distances (3 in. – 21 in.) and with different severity (1/8 in. – ½ in. hole)
- Lamb waves were sent through the plate by two sensors located at the ends of the plate

RESEARCH IMPACT

- Structural Health Monitoring in the aerospace industry is worth over $9 billion.
- Piezoelectric sensors in combination with the PCA method could reduce the cost of damage detection by 50%.

MAIN ACHIEVEMENT:



Signal and its Fast Fourier Transform due to a 13/32" hole at 3" away from Sensor 1

Fast Fourier Transform (FFT) Method

- The time domain signal is converted to a frequency domain signal
- The frequency domain signal can be integrated to find the energy of the signal

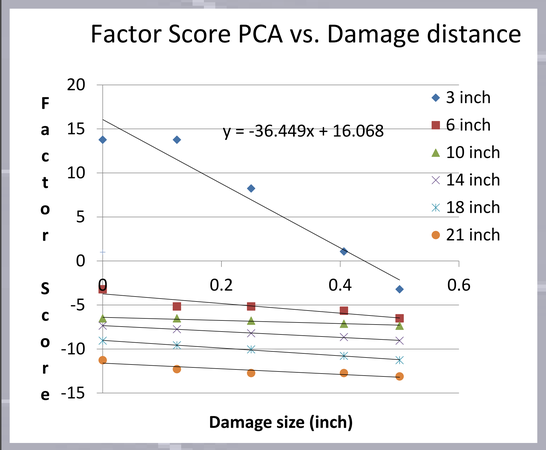
$$DI = \frac{Area_{Baseline} - Area_{Damage}}{Area_{Baseline}}$$

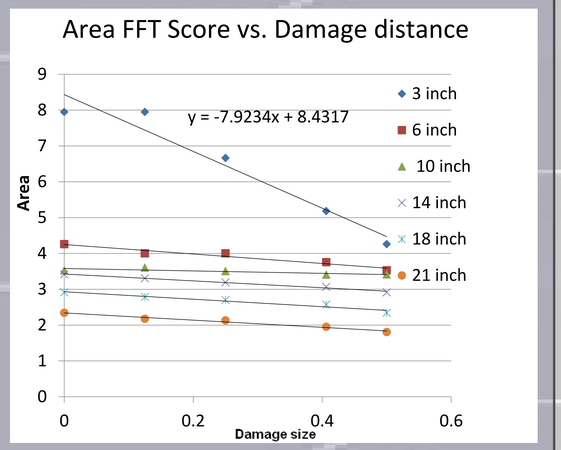
Principal Component Analysis (PCA) Method

- PCA is a method used to reduce the number of dimensions in an experiment
- Principal components are found by projecting the data onto the principal axes of the covariance matrix

Fast Fourier Transform (FFT) vs. Principle Component Analysis (PCA)

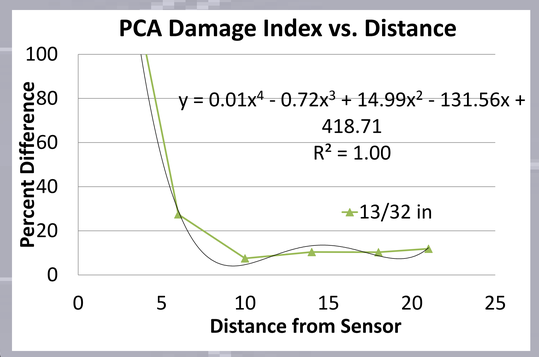
- A comparison of the slopes of the FFT and PCA methods of analysis show that for every increase in damage size, there is a much larger drop in factor score/area
- The PCA is much more sensitive

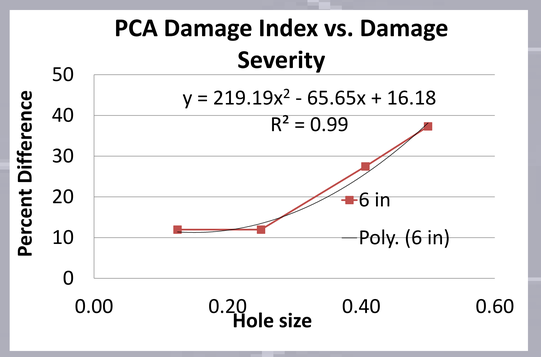




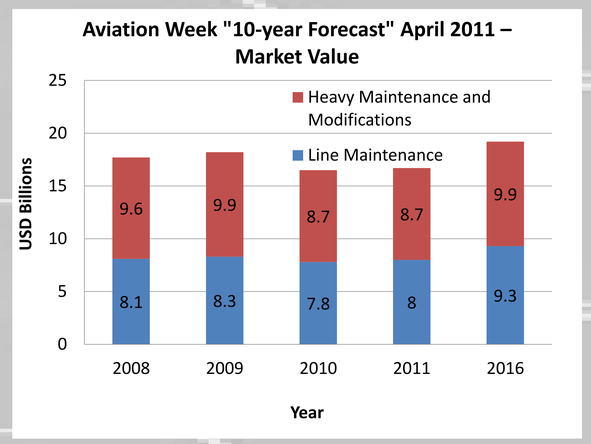
Future Inquiries with Principle Component Analysis (PCA)

- "Tail" of the PCA vs. Distance graph increases when a decrease is expected
- How sensitive is the measurement (How small are the damages this method can detect)?

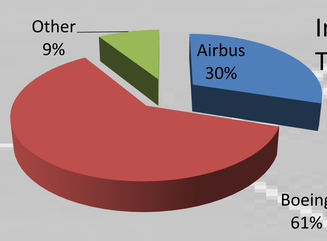




Economic Value



Market Value



International Air Transport Association

Possible Manufacturers

Why use piezoelectric sensors?

- By using smarter sensor systems, maintenance time can be cut by over 40%
- Most maintenance costs come from aircraft "down time"
- Cutting maintenance time costs directly cuts total costs

How does Principal Component Analysis add value?

- Fewer sensors result in lower fixed and installation costs

END-OF-PHASE GOAL

To be able to accurately detect damages.

- *Build a model to characterize the location and severity of damages in carbon fiber composites*

Example:

What is the distance of a 13/32 in. damage from sensor 1 with a DI percentage difference of 45%?

Solve for x using the equation from the PCA DI vs. Distance graph with y = 45%:

$$y = 0.01x^4 - 0.72x^3 + 14.99x^2 - 131.56x + 41871$$

The answer should be about 5 in.

Piezoelectric sensors would significantly reduce the cost of damage detection