Damage Detection, Quantification and Localization in X-COR Sandwich Composites using NDE/SHM

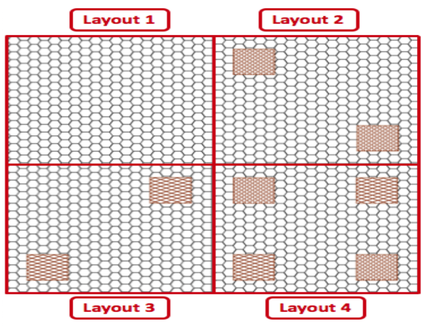
Guoyi Li, Abhishek Rajadas, Aditi Chattopadhyay
School for Engineering of Matter, Transport and Energy
AIMS Consortium Project, Sponsor: The Boeing Company, Technical Monitor: Daniel Huff

AIMS ADAPTIVE INTELLIGENT MATERIALS & SYSTEMS CENTER

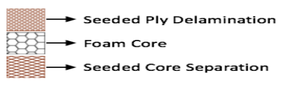
Project Objectives

- Advanced non-destructive evaluation (NDE) techniques to accurately & efficiently detect, localize & quantify damage in advanced X-COR composites
- Guided wave based structural health monitoring (SHM) methodologies and advance signal processing techniques for *in situ* damage detection and localization in real-time operation

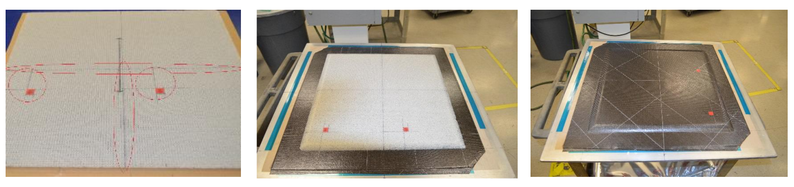
NDE Experiment Setup



Four layouts
- Layout 1: Pristine
- Layout 2: Seeded ply delamination only
- Layout 3: Seeded core separation only
- Layout 4: Both seeded ply delamination & seeded core separation

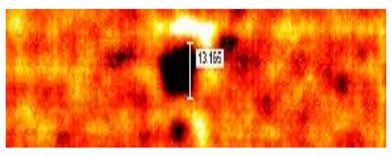


Manufactured in the Boeing facility

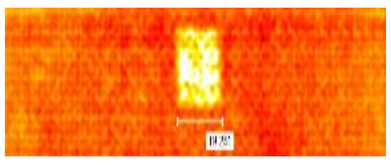


NDE - Thermography Inspection

Core separation size estimation

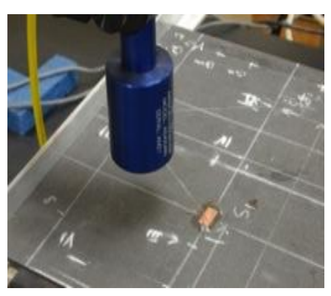


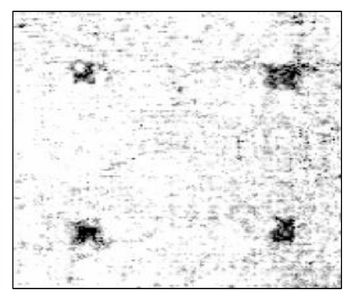
Delamination size estimation



- Size of delaminations successfully predicted within 1%
- Cannot penetrate foam core sufficiently; need to flip sample
- Inability to interrogate both sides of panel simultaneously
- Inaccuracy in measurement of core separation size

NDE - C-Scan Inspection

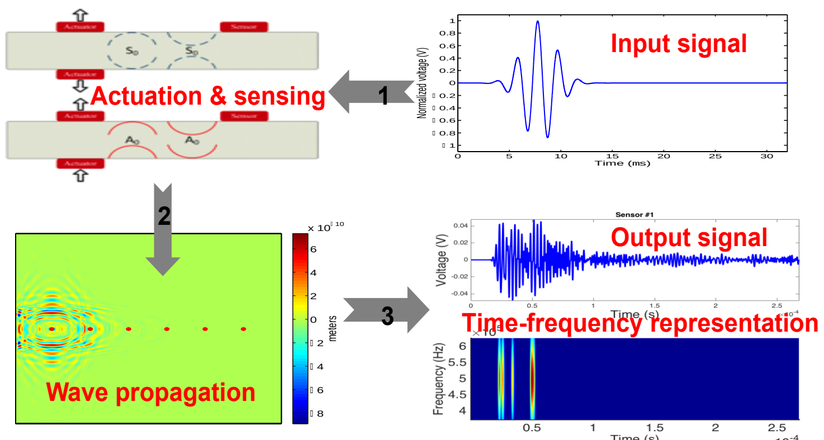




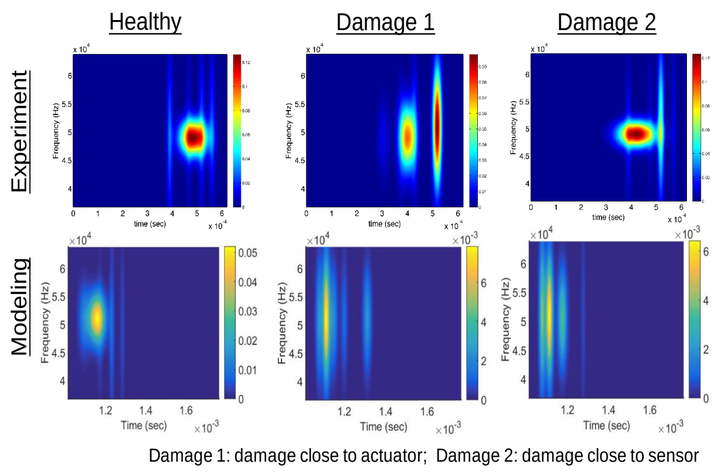
- Possible to detect all damage types in a single scan
- Sensitive to damages due to attenuating media (e.g. air gaps)
- Able to quantify both delaminations & foam core separations through thicknesses
- Difficulty remains in detecting top sheet core separations due to anomaly in surface structure
- Time consuming compared to flash thermography

SHM - Guided Wave Modeling

- Determine the excitation frequency & signal type
- Selective actuating method for isolating wave modes
- Finite difference based local interaction approach
- Signal processing using Matching Pursuit Decomposition



SHM Results – Modeling vs. Experiments



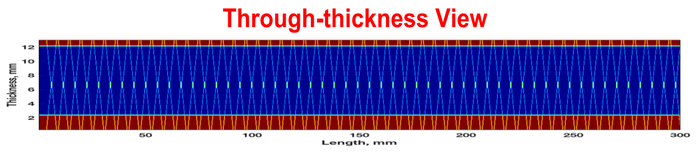
Damage 1: damage close to actuator; Damage 2: damage close to sensor

- Mode conversion due to structural delamination
- Modeling result has a good agreement with experimental results
- Modeling technique effectively reduces the experimental efforts

SHM - Non-homogenized Model

- Model the pins explicitly without material homogenization
- Investigate the effects of pins on wave propagation

Through-thickness View

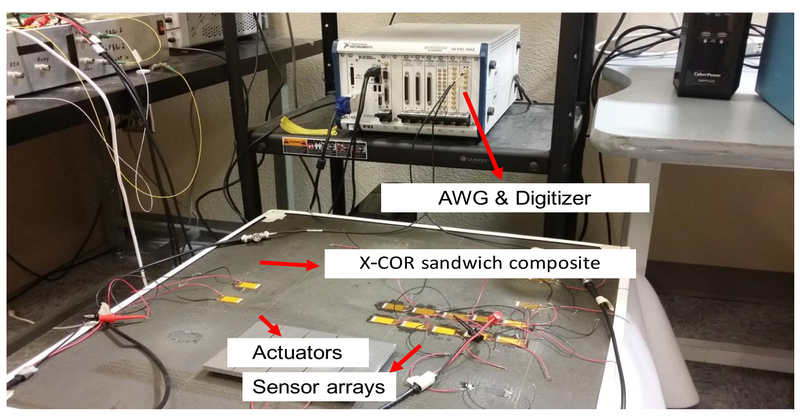


Displacement Contours

- Additional attenuation introduced due to presence of pins
- Necessary to consider this effect in SHM for X-COR sandwich structures

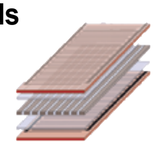
Guided Wave Based SHM - Experiment Setup

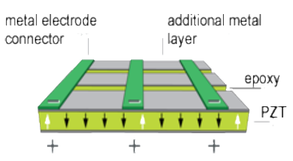
- MFC sensor arrays constructed on the surface
- Each array: 1 actuator & 5 sensors
- Actuating signal: 5-cycle cosine tone burst with frequencies from 10 kHz to 120 kHz
- Delaminations (25 mm x 25 mm) at mid-layer of facesheet



Macro Fiber Composite (MFC)

- Consists of rectangular piezoceramic rods sandwiched between layers of adhesive, electrodes and polyamide film
- Sealed package ensures durability
- Bonded to various structures or embedded in a composite structure
- Dual electromechanical capability: converts Voltage to Strain and vice-versa
- M2814-P2 MFCs used in this study
  - Dimensions: 28mm x 14mm
- Advantages
  - Flexibility
  - Directional actuation
  - Conformability



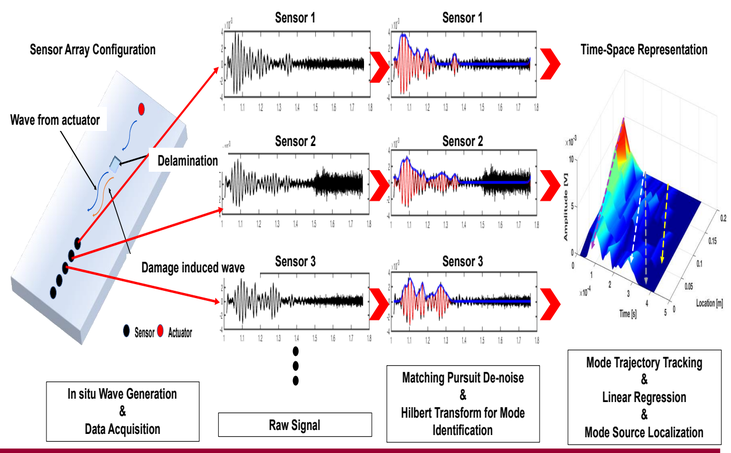


www.smart-material.com

Wilkie W 2003 Method of fabricating a piezoelectric composite apparatus U.S. Patent No. 6.629.341

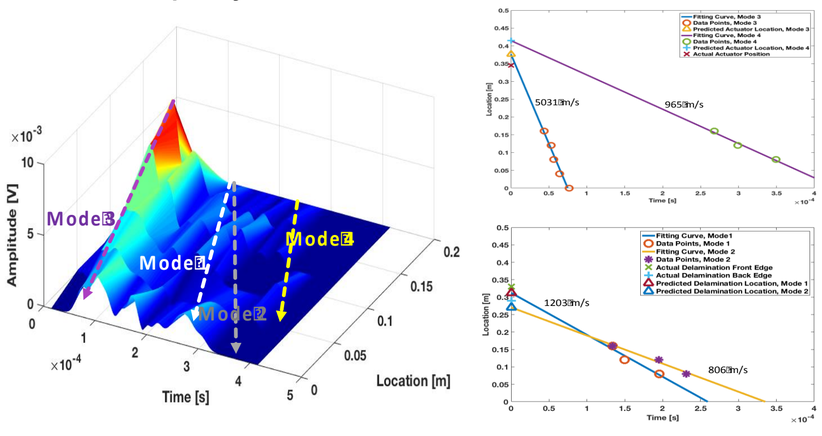
Damage Localization Schematic

- Difficulties in detecting reflected waves due to high dispersion
- Novel mode tracking based damage localization method
- Signal de-noising in time-frequency domain
- Damage localization in time-space domain without baseline information (reference free)



Damage Localization Under 70 kHz

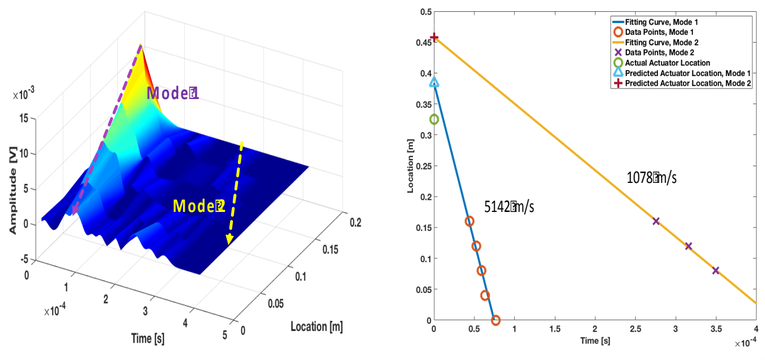
- Excitation frequency: 70 kHz



- Features (amplitudes, velocities, etc.) successfully identified in time-space representation
- Actuator and delamination accurately localized

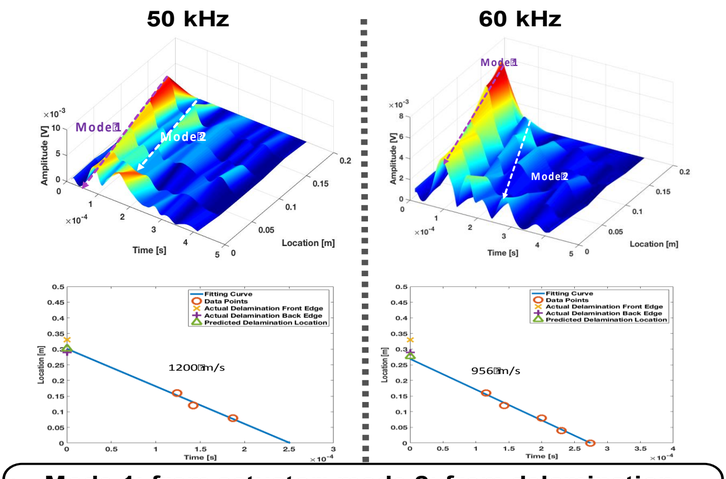
Comparison with Healthy Path

- Time-space representation of healthy path



- 2 modes found and identified as wave from actuators
- Comparing with damaged case, delaminations have minor impacts on velocities of original waves
- Amplitudes reduced due to presence of delaminations

Repeatability under Various Frequencies



- Mode 1: from actuator; mode 2: from delamination
- Algorithm shows robustness for damage localization under various of excitation frequencies

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