**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

- 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, gels)
- 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**

- Healthy
- Damage 1
- Damage 2
- Through-thickness View

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

**SHM - Non-homogenized Model**

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

- 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 (28 mm x 25 mm) at mid layer of facesheet

**Macro Fiber Composite (MFC)**

- Consists of rectangular piezoelectric rods sandwiched between layers of adhesive, electrodes and polyyamide 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

**Damage Localization Schematic**

- Difficulties in detecting reflected waves due to high dispersion
- Novel mode tracking based 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

**Comparison with Healthy Path**

- Time-space representation of healthy path

**Repeatability under Various Frequencies**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>50 kHz</th>
<th>60 kHz</th>
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<tbody>
<tr>
<td>Mode 1:</td>
<td>Feature (amplitude, velocity, etc.) successfully identified in time-space representation</td>
<td></td>
</tr>
<tr>
<td>Mode 2:</td>
<td>Actuator and delamination accurately localized</td>
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</tbody>
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**ADAPTIVE INTELLIGENT MATERIALS & SYSTEMS CENTER**