Composite characterization using laser Doppler vibrometry and multi-frequency wavenumber analysis

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Motivation

Composite Solutions Applied Throughout the 787

- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylon

- Steel: 10%
- Titanium: 15%
- Aluminum: 20%
- Other: 5%
- Composites: 50%
Motivation

Barely Visible Damage (BVD)

IM7/8552(10) 15x15 2G-PLY

(0/45/-45/90)3/0]

O7MAY12

#2/8

0°
Motivation

- Low velocity impact
- Ply layers
- Carbon fiber composite
Goal of research

- 26 ply carbon fiber panel 15”x15”, quasi-isotropic layup ([0/45/-45/90]_3/0)_s

- Damaged using a static point load of 1511 lbf until failure, then scanned using a traditional nondestructive evaluation technique (ultrasonic immersion tank scanning)
Data was collected from a Scanning Laser Doppler Vibrometer (SLDV) while acoustic waves were excited in the panel with a contact transducer.

Goal: to correlate the SLDV data to the size and depth of the delaminations in the composite.
What are we detecting?
What are we detecting?

Lamb wave

1/wavelength = wavenumber
What are we detecting?

Delamination
Any relationship between wavenumber and location is lost.
Local wavenumber technique

Wavefield data over time
Local wavenumber technique

 FFT

 Wavefield data over time

 Wavefield data over frequency

 Time

 Frequency
Local wavenumber technique

Wavefield data over frequency
Local wavenumber technique
Local wavenumber technique

2D FFT

$X$ $Y$

$X$ $Y$

$k_x$ $k_y$
Local wavenumber technique

Slide 11.3
Local wavenumber technique
Local wavenumber technique
Local wavenumber technique
Window size
Window size

![Diagram showing a color map with a label for 1.4mm and a plot of oscillatory patterns with a boxed area highlighting a specific section.](image)
Window size

[Image of a window size diagram with coordinates and color scale]

Next: Dechirp
Dechirp process

Data recorded using chirp excitation

Chirp Excitation Signal

Desired single frequency signals

\[ u(x, y, t) = \mathcal{F}^{-1} \left[ \frac{\mathcal{F}(R_c(x, y, t))}{\mathcal{F}(S_c(x, y, t))} * \mathcal{F}(S_d(x, y, t)) \right] \]

Single frequency excitation data
Differences in frequencies: Wavefields

200kHz

300kHz

400kHz

500kHz

x (mm)

y (mm)
Differences in frequencies: Wavenumber

Next: Dispersion curves
Multi-frequency wavenumber-ply correlation

\[ k(x, y, f) \]

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Multi-frequency wavenumber-ply correlation
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Multi-frequency wavenumber-ply correlation

\[ \text{Ply}(x, y) \approx \text{Ply}_2 \]
Ply correlation results

- Correlation frequency range: 300kHz-400kHz in 5kHz steps
- 10mm window
- 0.3mm spatial resolution
- 20MHz sampling rate
Ply correlation results
Sources of error: standard deviation
Sources of error: dispersion curves
The local wavenumber technique is capable of very accurate determination of the shape and size of interlamina damage in composite panels, especially when considering multiple frequencies.

Using multi-frequency wavenumber-ply correlation can determine the depth location of damage in many instances, but struggles with deeper and smaller delaminations.

Future research will be conducted to improve this methodology using wave domain filtering, better dispersion curve generation, and more robust correlation methods.
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