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

By Peter Juarez and Dr. Cara Leckey

NASA Langley Research Center
Nondestructive Evaluation Sciences Branch
Motivation

Composite Solutions Applied Throughout the 787

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

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

Barely Visible Damage (BVD)
IM7/8552(10) 15 x 15 2G-Ply

[(0/45/-45/90)]
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)
Normal to YZ plane

Normal to XY plane
Goal of research

- 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

$\frac{1}{\text{wavelength}} = \text{wavenumber}$
What are we detecting?

Delamination
Wavenumber Domain Analysis

Sample time domain wave field

Any relationship between wavenumber and location is lost
Local wavenumber technique

Wavefield data over time

Time

X (mm)  Y (mm)

0  0  50  50  100  100  150  150  200  200
Local wavenumber technique
Local wavenumber technique

Wavefield data over frequency
Local wavenumber technique
Local wavenumber technique

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2D FFT

Slide 11.2
Local wavenumber technique

2D FFT

k_x k_y

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Local wavenumber technique
Local wavenumber technique

2D FFT

$\mathbf{X}$ $\mathbf{Y}$

$k_x$ $k_y$
Local wavenumber technique

2D FFT

2D FFT

$2D FFT \rightarrow k_x \rightarrow k_y$
Local wavenumber technique
Window size
Window size
Window size
Dechirp process

Data recorded using chirp excitation

Chirp Excitation Signal

Desired single frequency signals

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

Single frequency excitation data

Desired single frequency signals
Differences in frequencies: Wavefields

- 200kHz
- 300kHz
- 400kHz
- 500kHz
Differences in frequencies: Wavenumber

350kHz

400kHz

450kHz

500kHz

550kHz

750kHz

Next: Dispersion curves
Multi-frequency wavenumber-ply correlation

\[ k(x, y, f_1) \]

\[ k(x, y, f_2) \]

\[ k(x, y, f_3) \]

\[ k(x, y, f_4) \]
Multi-frequency wavenumber-ply correlation

Diagram showing the relationship between wavenumbers $k_1, k_2, k_3,$ and $k_4$ against frequencies $f_1, f_2, f_3,$ and $f_4$.
Multi-frequency wavenumber-ply correlation

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Multi-frequency wavenumber-ply correlation
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

[Image showing a color-coded diagram with labels A, B, C, 10/11, 14/15, 15/16, 16/17, 17/18, 6/7, 7/8, 9/10.]

Next: Dispersion curve
Sources of error: standard deviation
Sources of error: dispersion curves
Conclusions

- 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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