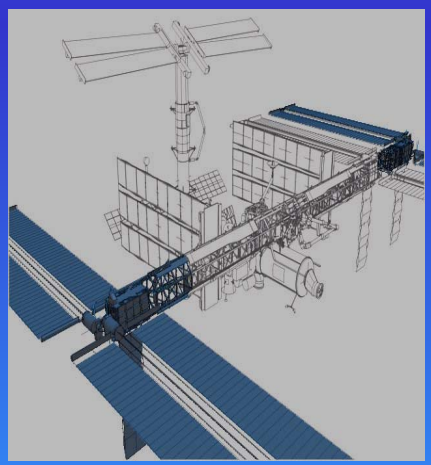
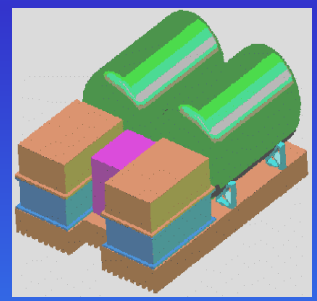
Glenn Research Center

Ultrasonic and X-ray NDE Characterization of Flywheel Composite Rims

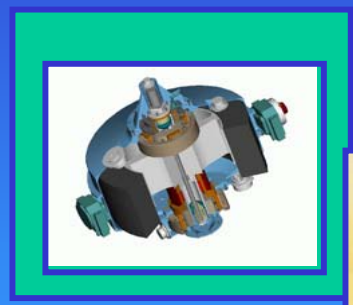
UT - CEM

George Y. Baaklini
NASA Glenn Research Center g.y.baaklini@grc.nasa.gov
Richard E. Martin and Laura M. Harmon
Cleveland State University
r.e.martin@grc.nasa.gov and l.m.harmon@grc.nasa.gov
Richard Thompson
UT CEM
r.thompson@mail.utexas.edu





RSL Workshop 03/14-15/02



NDE Development for Composite Rings and Rims

Objectives

Establish a necessary understanding of UT CEM filament wound composite rim architecture and manufacturing tolerances to develop:

- **Damage tolerance criteria-**
  manufacturing & testing induced flaw sensitivities to structural reliability
- **Quality assurance inspection criteria-**
  critical initial flaw sizes and flaw types
- **NDE plan for flight hardware-**
  Latest 3 papers by the authors are summarized herein

Glenn Research Center

NDE Plan for Flight Hardware

UT - CEM

I. **Rim and ring NDE standards to accompany all inspected parts :**

Calibration standards with known defects are utilized to assure NDE resolution and detection capabilities as well as the reliability of test equipment during all NDE tests and certifications:

1 inch thick representative rim (s) with nested rings √

1/2 inch thick representative ring (s)

II. **NDE imaging methods employed for rings and rims:**

1. PE ultrasonic scans from the side toward the center of rotation for single rings and full rims √

2. Microfocus X-ray film radiography of all rings only

3. Selected X-ray CT slices of rings based on NDE findings from 1 & 2 above √

4. X-ray CT slices of full rims parallel and perpendicular to axis of rotation √

III. **NDE Methods employed for Material Characterization:**

1. Angular pitch-catch ultrasonic for assessment of last two rings and interfaces or

2. Acousto-ultrasonics decay rate before and after mechanical testing for degradation assessment and/or

3. Ultrasonic resonance spectroscopy √

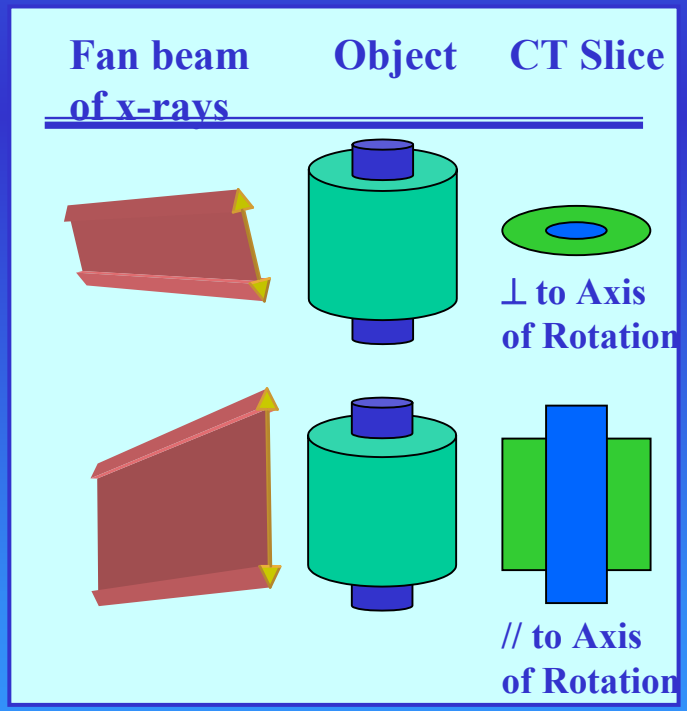
Glenn Research Center

NDE Standards and NDE Imaging and Material Characterization Methods Are Utilized

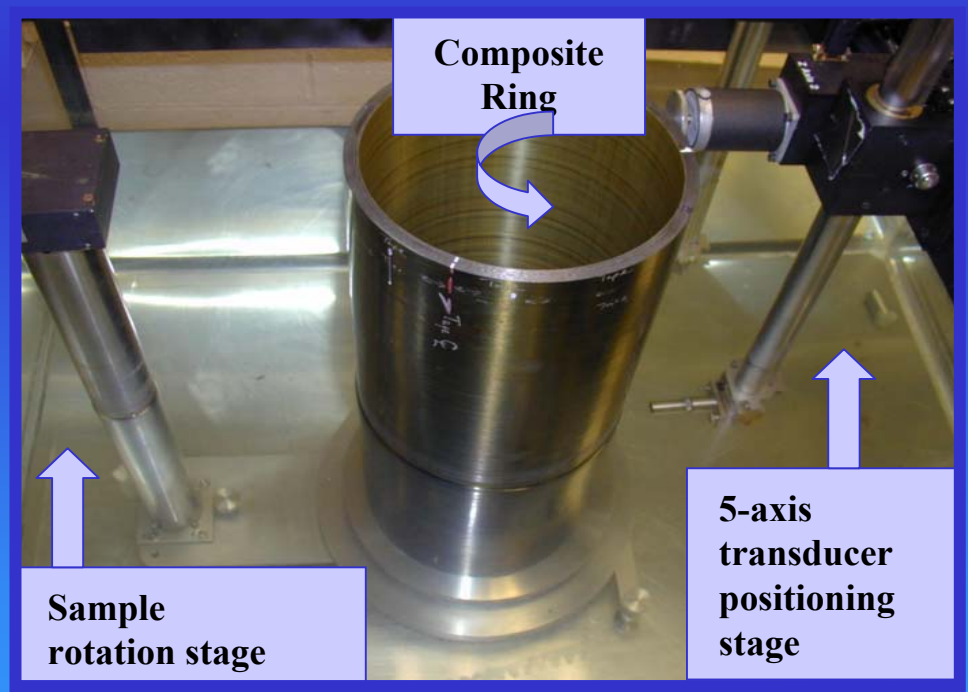
UT - CEM

- Imaging methods include ultrasonic, radiographic and tomographic scans
- Characterization methods include normal and angular incidence ultrasonic, acousto-ultrasonics, and ultrasonic resonance spectroscopy

Computed Tomography



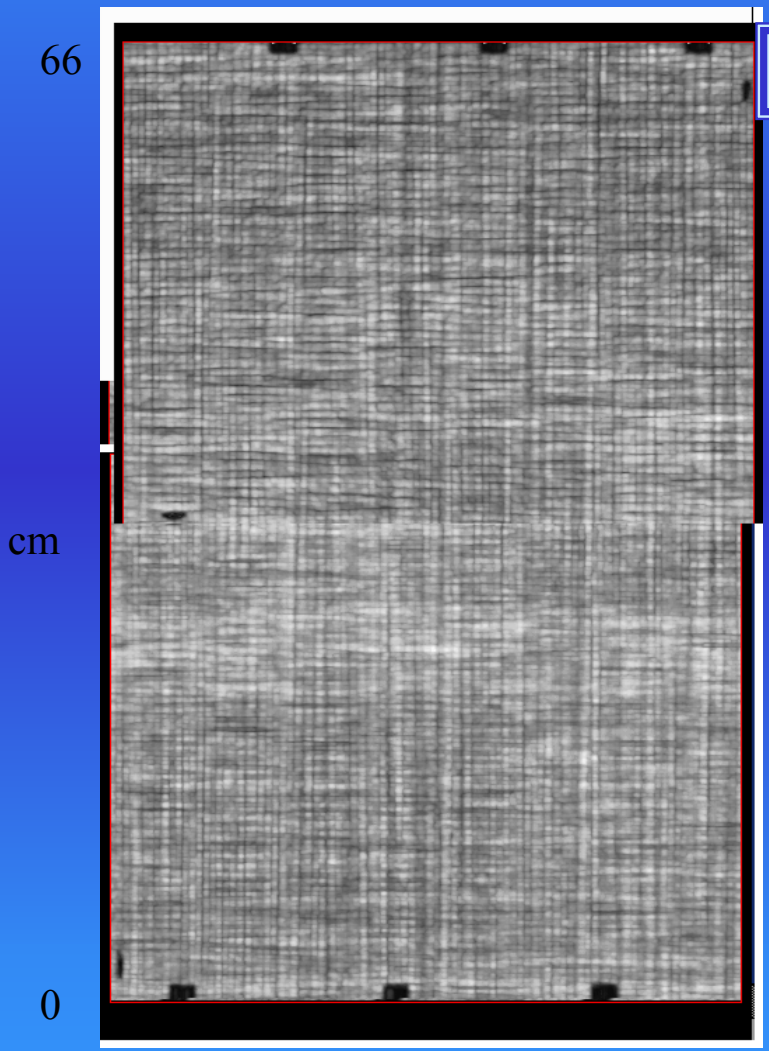
Pulse-Echo Ultrasonics



Glenn Research Center

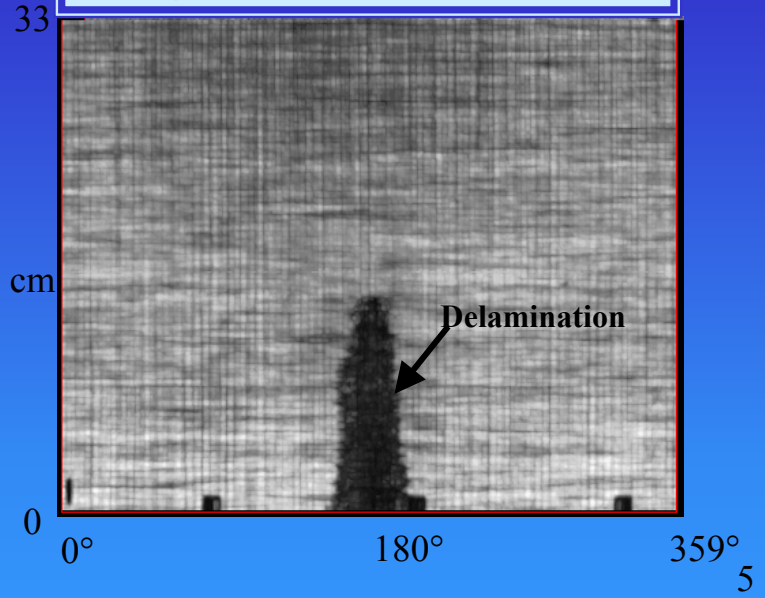
Ultrasonic scans showing a healthy ring and a flawed ring

UT - CEM



Healthy ring

Ring with a delamination



5

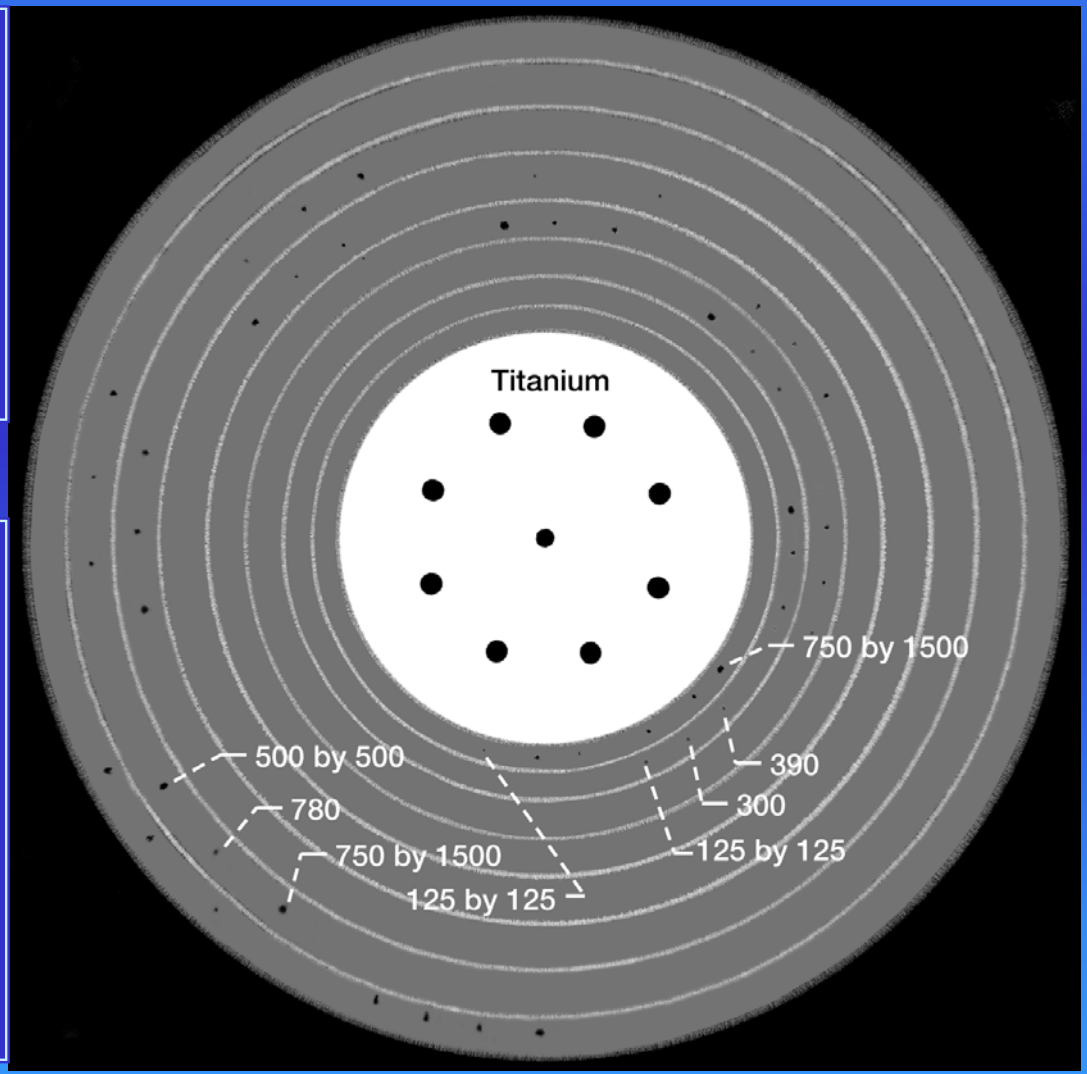
Computed Tomography Slice Through Titanium and Polymer Matrix Composite Rim

Glenn Research Center

UT - CEM

- 10.5” O.D.
- 4” Diam. of Titanium
- 3.5” of annulate Composites

- All bottom drilled holes and EDM notches were detected down to 125x125 micrometers (5x5 mils)



Glenn Research Center

ULTRASONIC SPECTROSCOPY (Resonance Effects)

UT - CEM

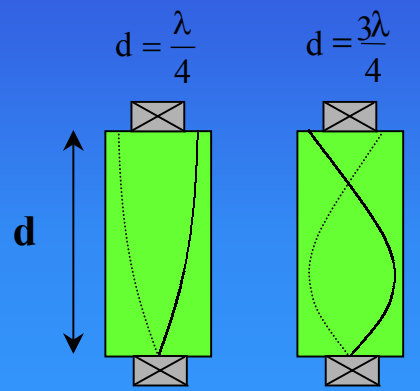
- Standing waves introduced in the material will result in constructive and destructive interferences.
- Constructive interference will occur at even quarter wavelengths in the material relative to the thickness while waves will cancel at odd quarter wavelengths.

$$f = c / \lambda$$

f is frequency
c is acoustic velocity and
λ is wavelength

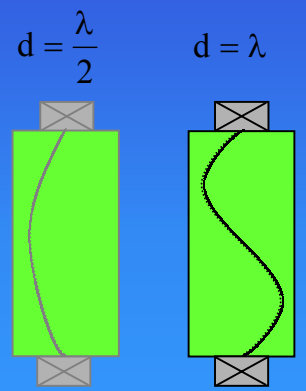
The fundamental resonant frequency in a material will occur when $d = \lambda / 2$, therefore

$$f_R = c / 2d$$



Odd Quarter Wavelengths Cancel

Even Quarter Wavelengths Resonate

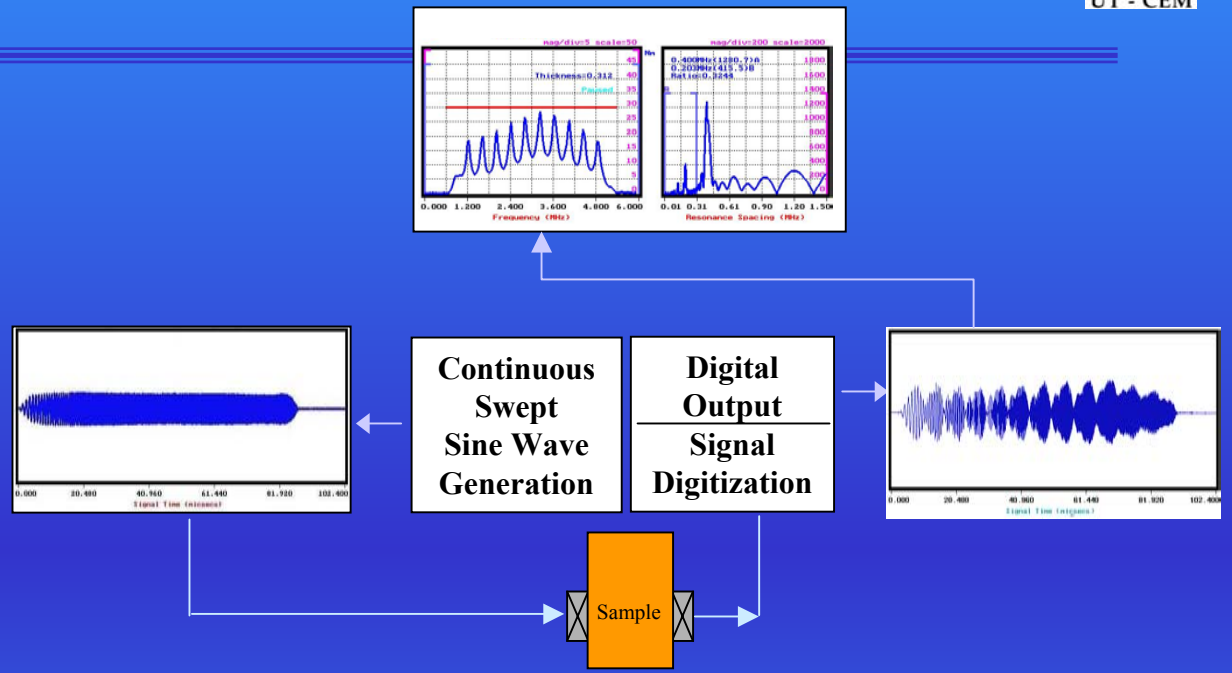


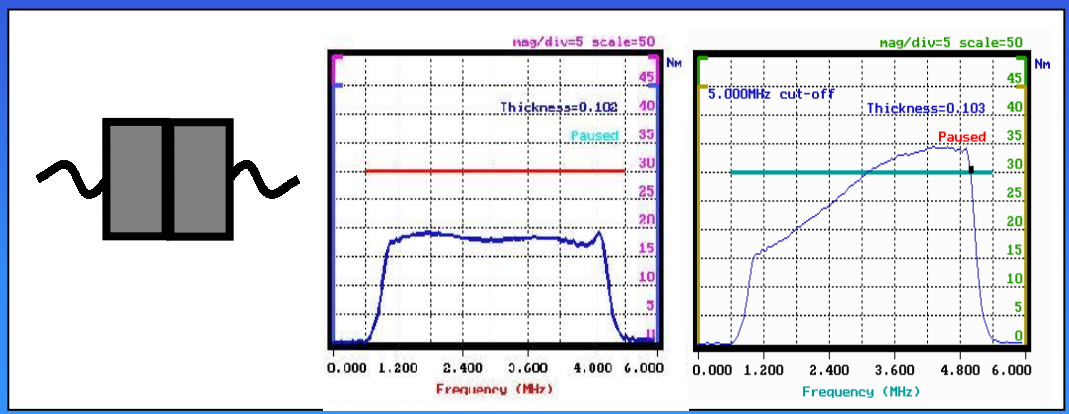
Ultrasonic Resonance Spectroscopy

Glenn Research Center

UT - CEM

Frequency sweep capabilities from audible range to 8 MHz





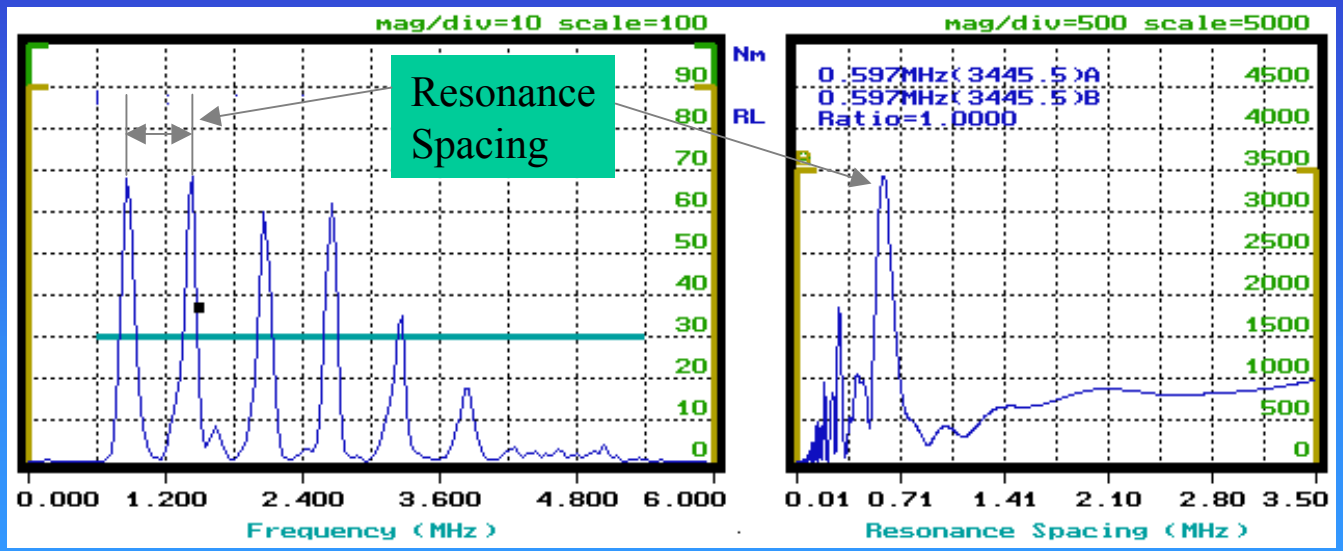
Equalization and adjustment of input signal

ULTRASONIC SPECTROSCOPY (Resonance Effects)

Glenn Research Center

UT - CEM

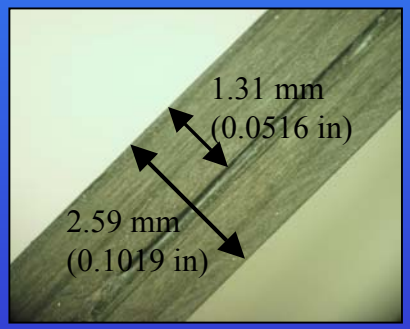
- Integer multiples of the fundamental will also resonate.
- Distance between resonant peaks will therefore be a measure of the fundamental frequency.
- An FFT of the transducer response to the sweep input will show the resonant peaks in the frequency domain.
- A second FFT will measure the frequency, or spacing, of the peaks in the frequency domain.
- Analysis of the amplitudes and frequencies of these peaks is used for the detection of flaws or degradation in materials.



One Layer Composite Ring with Intentional Delamination

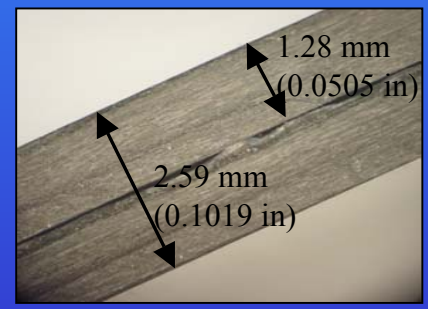
Glenn Research Center

UT - CEM

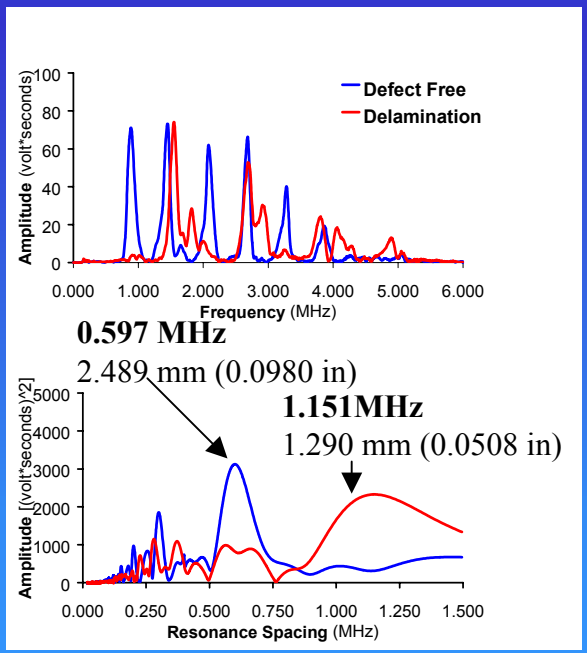


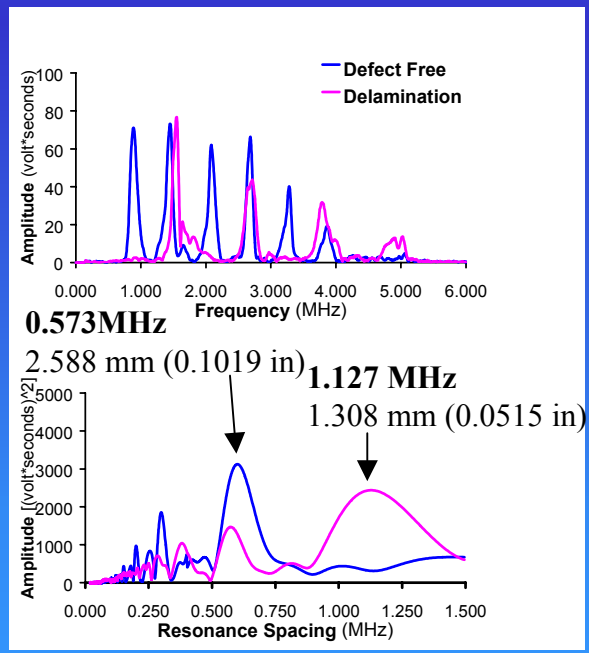
Optical Photo

- Location of delamination determined from the resonance within a 2.5% error compared to optics
- Delaminations of different structure produced response signals with different features



Optical Photo



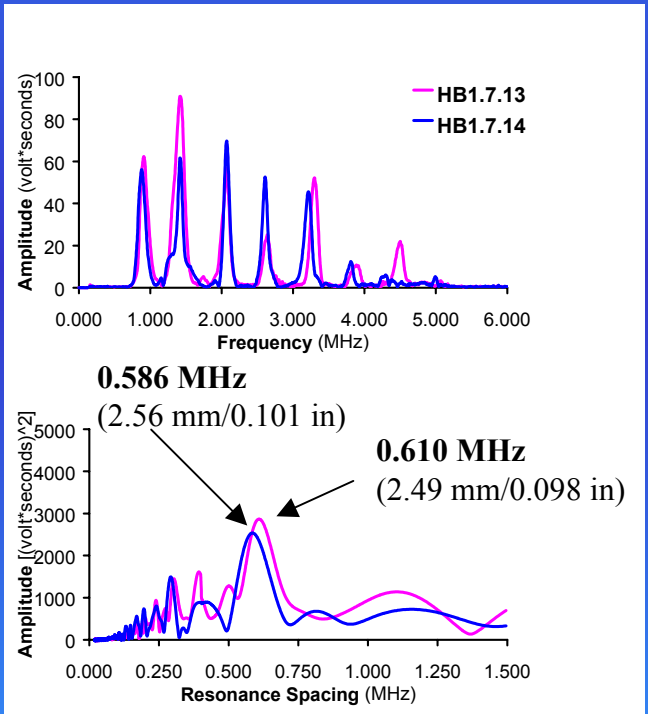


Three-Layer-Composite Rings and Flat Coupon

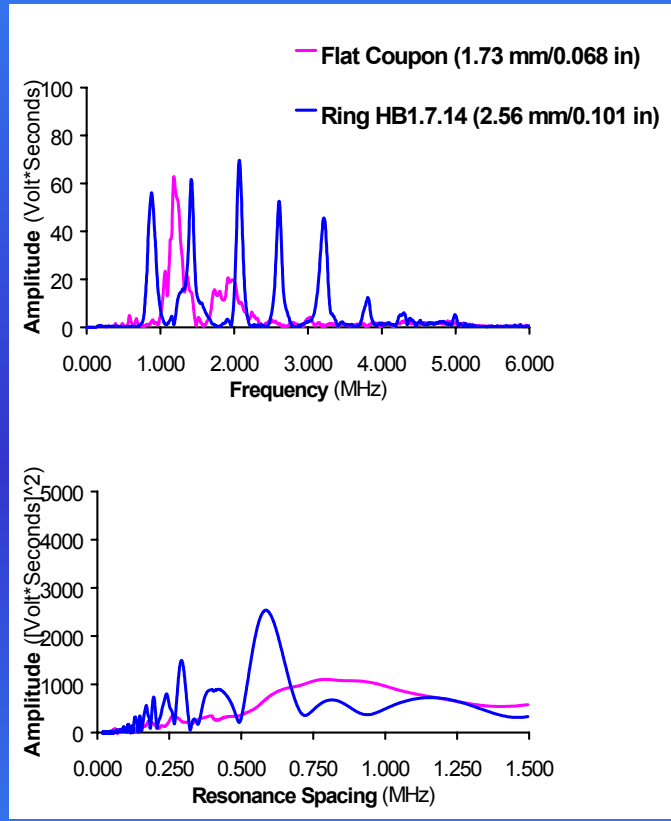
Glenn Research Center

UT - CEM

Typical Spectrum and Spectrum Resonance Spacing for defect free three-layer-composite rings



The full thickness resonance appeared for both rings



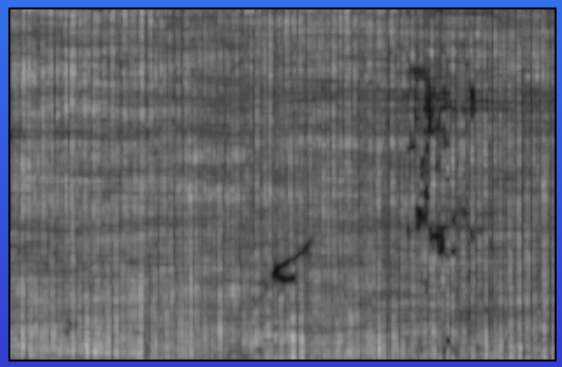
Manufacturing of the flat coupon did not duplicate the manufacturing of the thin composite rings.

Individual and Cluster of Voids in Ring R2.6

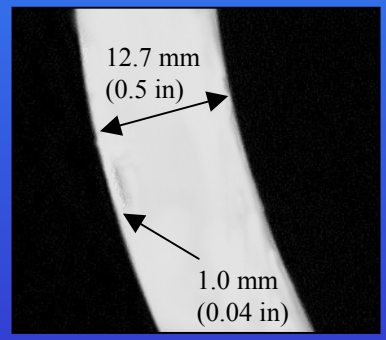
Glenn Research Center

UT - CEM

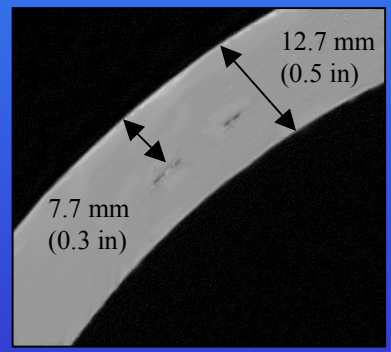
Ultrasonic Scan



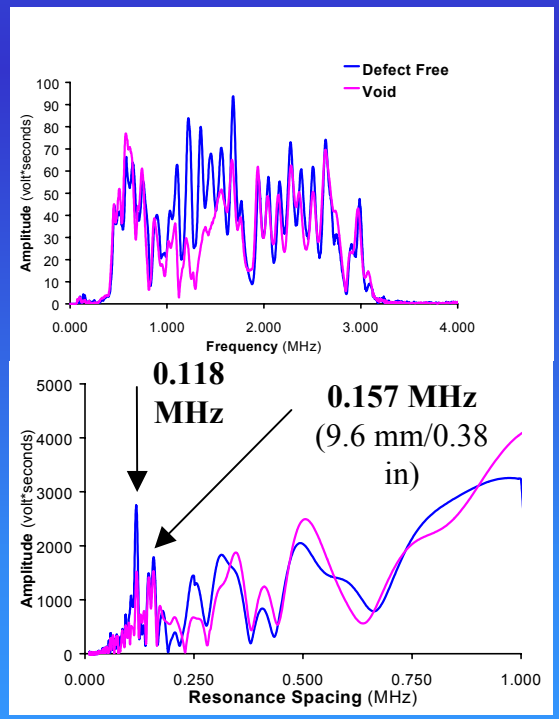
CT Slice

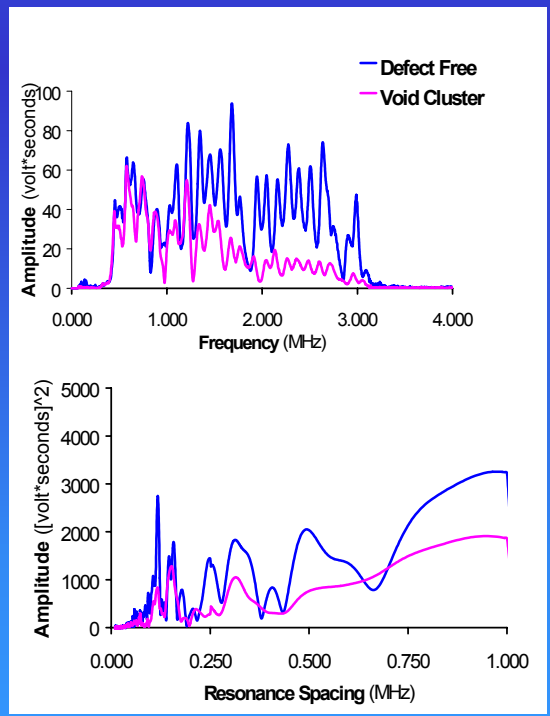


CT Slice



- Responses for the defect free region indicated possible kissing disbonds not yet confirmed with other methods
- The void and void cluster reduced amplitude of full thickness resonance by 40% and 60%, respectively
- Resonances indicating the locations of the void and void cluster did not appear

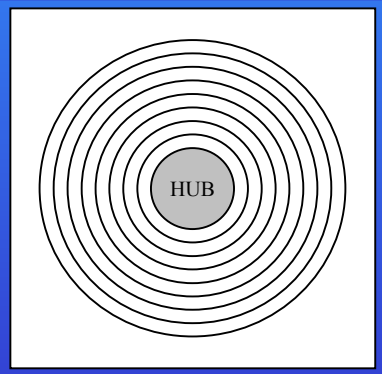




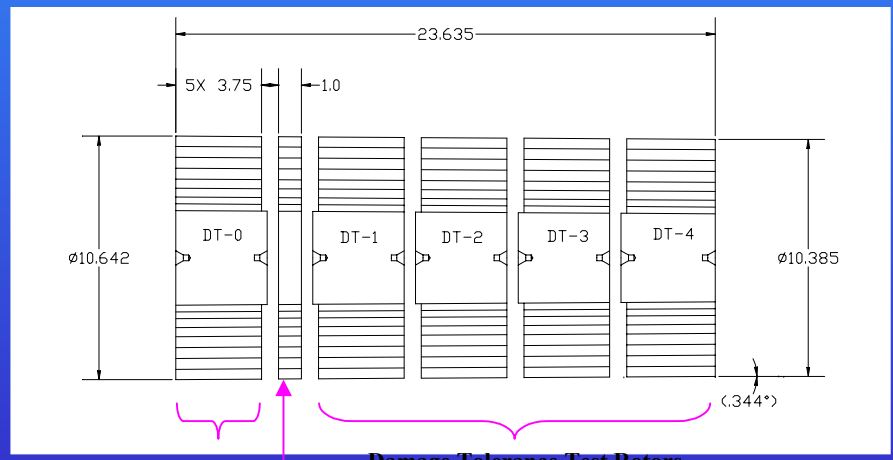
Glenn Research Center

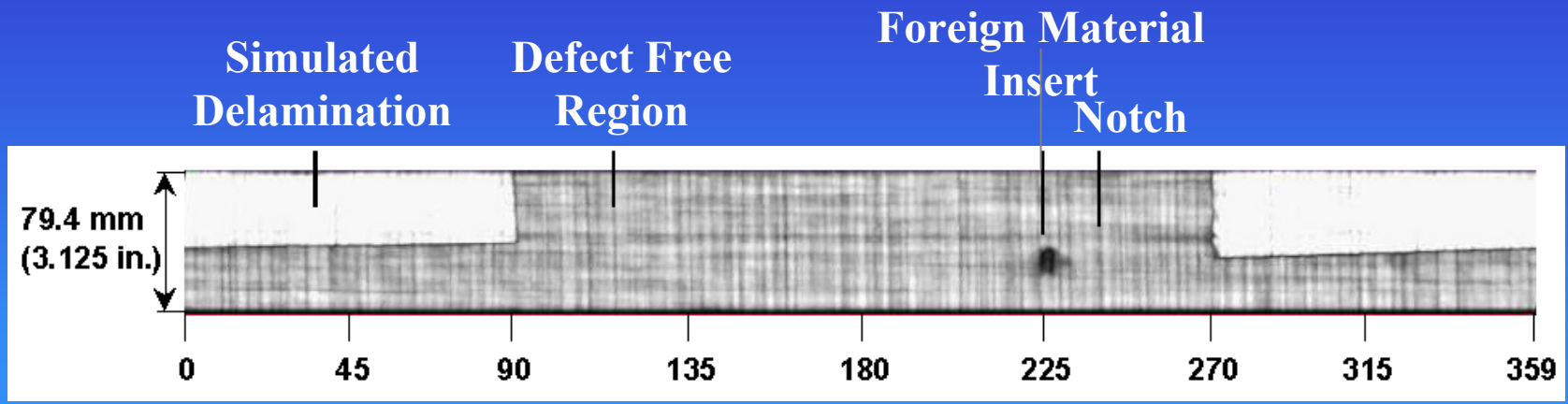
Control and Developmental Rotors

UT - CEM



Four Rims Made of Concentric Composite Rings





Ultrasonic C-Scan of a Developmental Composite Rim

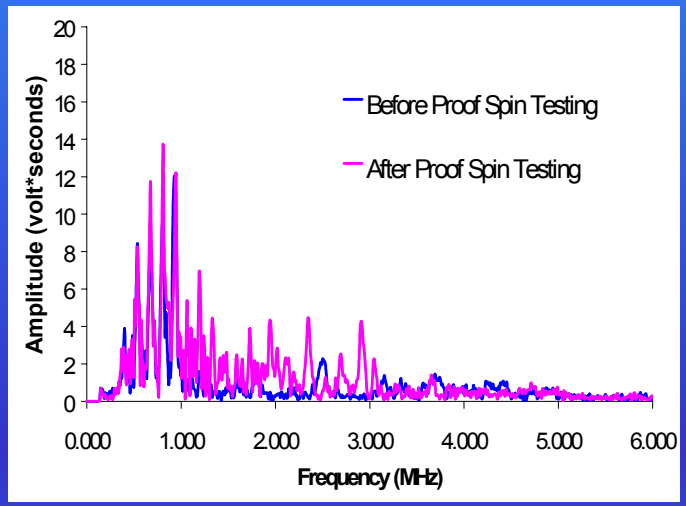
Multi-Ring Defect Free Rim
Before and After Proof Spin Testing

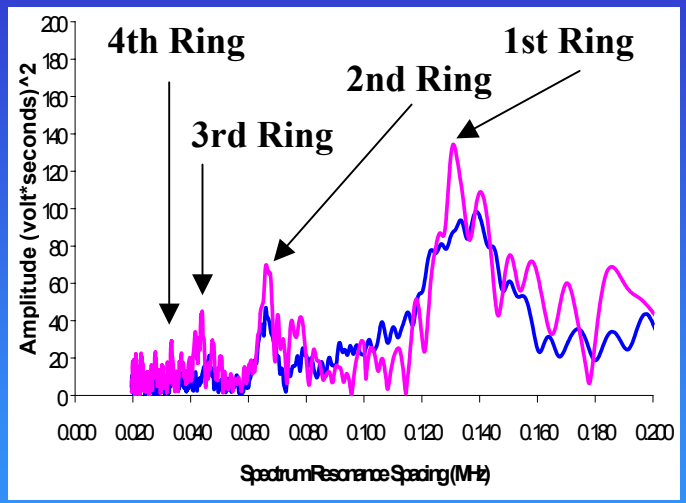
Glenn Research Center

UT - CEM

- Resonant Frequencies for the four outer rings:
  - 0.132 MHz (11.1 mm from O.D.)
  - 0.067 MHz (23.7 mm from O.D.)
  - 0.044 MHz (36.2 mm from O.D.)
  - 0.033 MHz (48.2 mm from O.D.)

  detected establishing the opportunity for health monitoring
- Similar resonant frequencies before and after proof spin testing, indicating successful manufacturing of a sound multi-ring composite rim
- In agreement with pulse-echo scans and x-ray tomography NDE
- These resonances will be observed after fatigue testing for interfacial damage degradation between and within rings
- Full thickness resonance was not detected



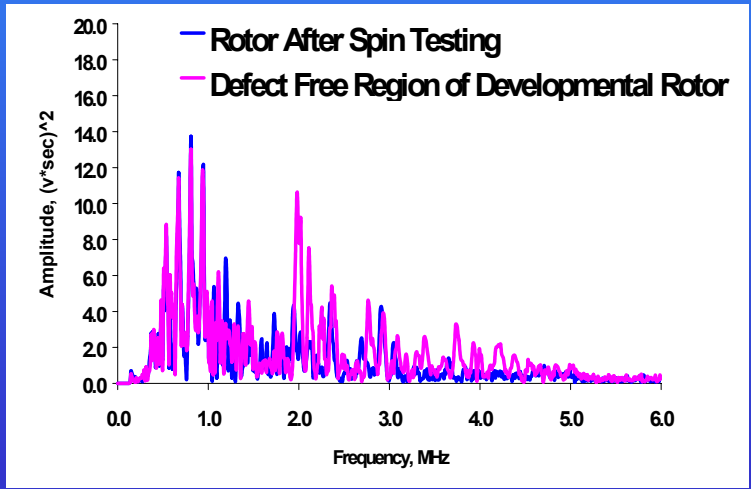


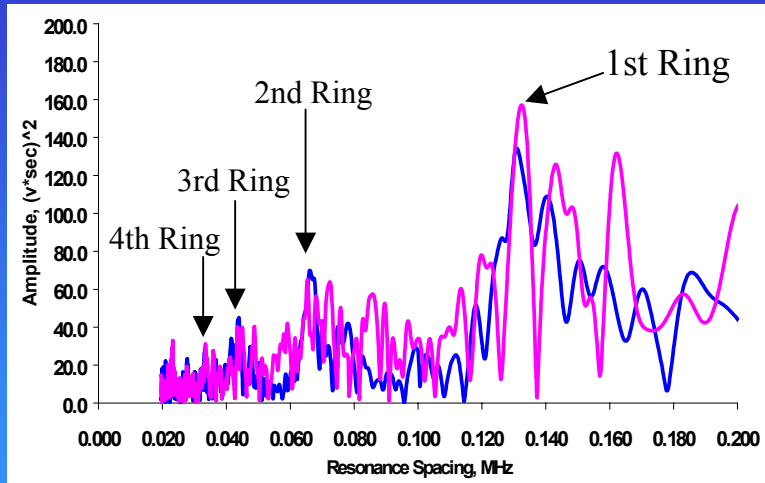
Glenn Research Center

Previous Results vs New Results

UT - CEM

- Similar resonances indicating successful manufacturing of the developmental composite rotors
- Responses from the defect free region of the developmental composite rotors will act as baseline signals for this study
- Resonances will be observed to determine how different types of damage in the outer ring are detected with ultrasonic spectroscopy



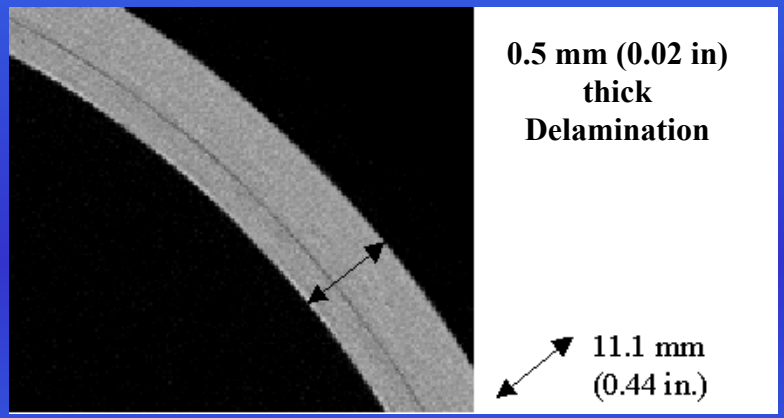


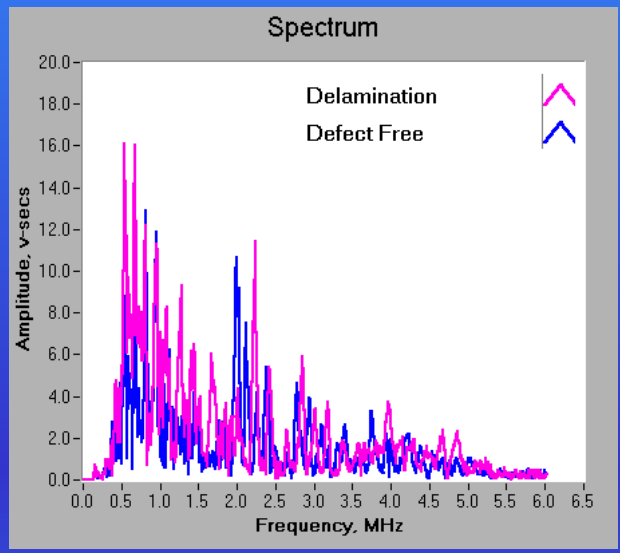
Glenn Research Center

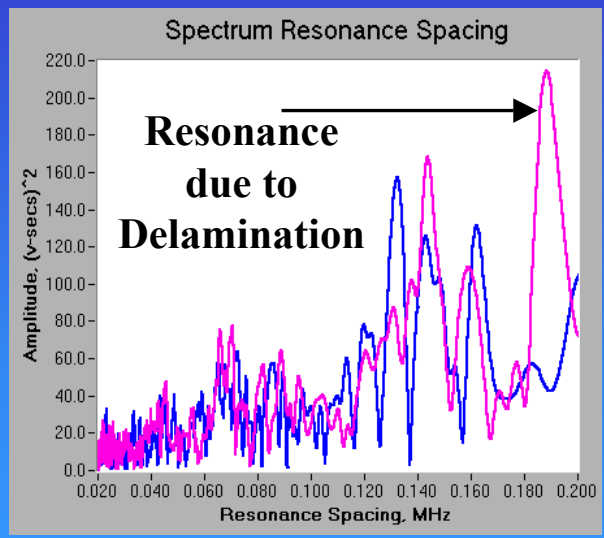
Simulated Delamination

UT - CEM

Computed Tomography Image of the Simulated Delamination in the Outer Ring







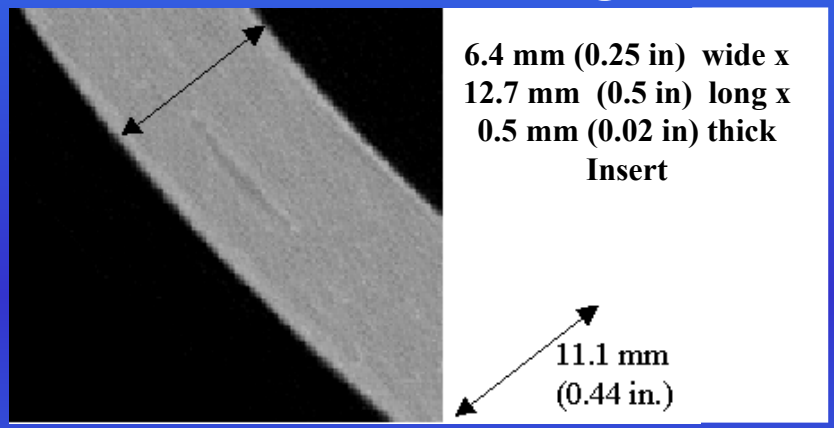
- New resonance corresponding to location of delamination appears at 0.188 MHz
- Outer rings' resonance shifts to 0.144 MHz

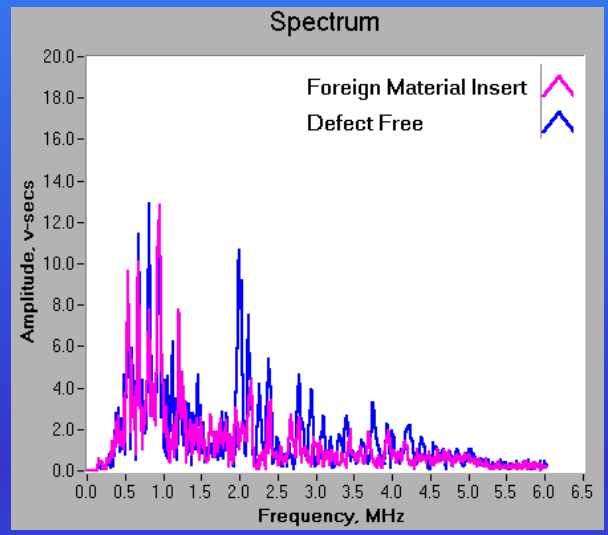
Glenn Research Center

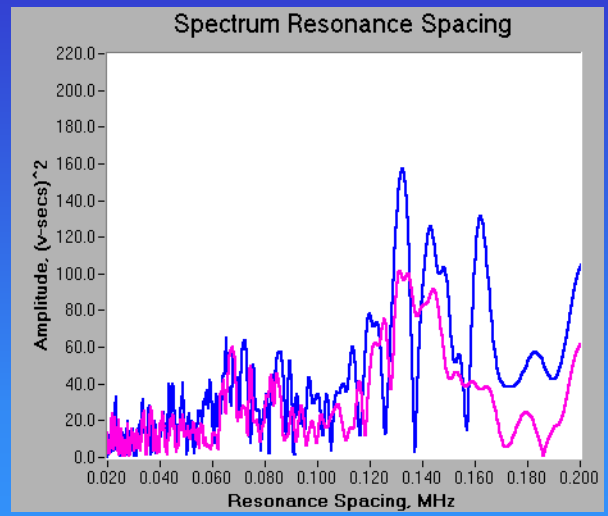
Foreign Material Insert

UT - CEM

Computed Tomography Image of the Foreign Material Insert in the Outer Ring







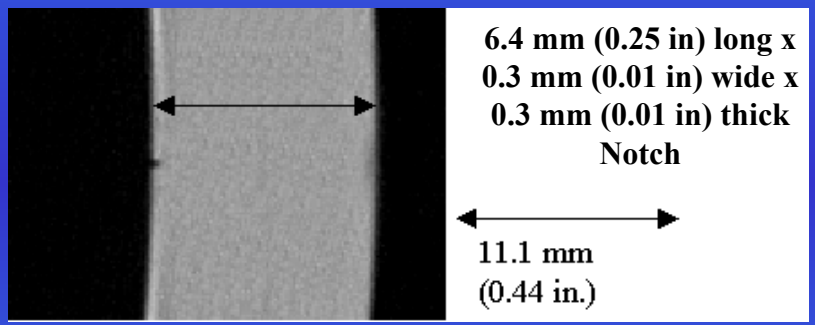
- Spectrum Resonance Spacing Domain had an overall reduction in amplitude
- A reduction in a the amplitudes of frequencies beyond 1.5 MHz occurred in the spectrum domain
- Detected foreign material insert without prior knowledge

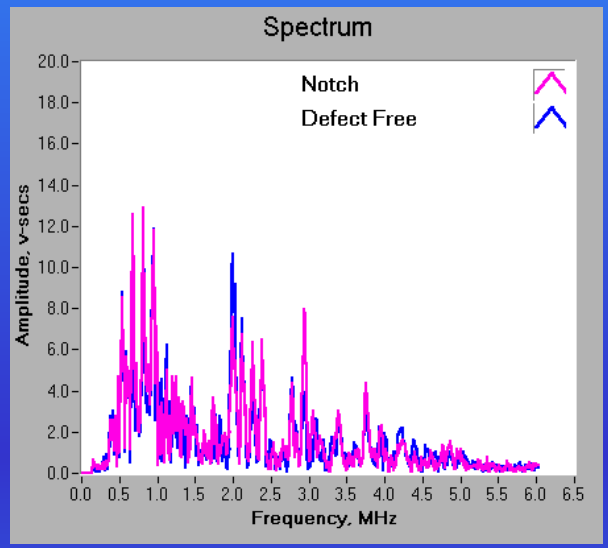
Glenn Research Center

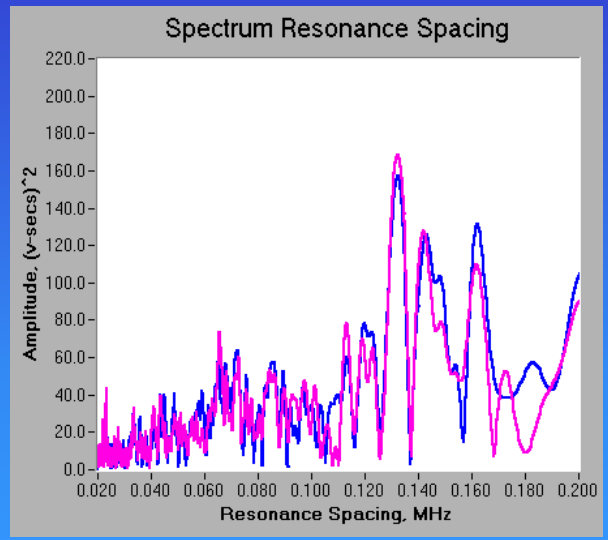
Notch

UT - CEM

Computed Tomography Image of the Small Notch in the Outer Ring





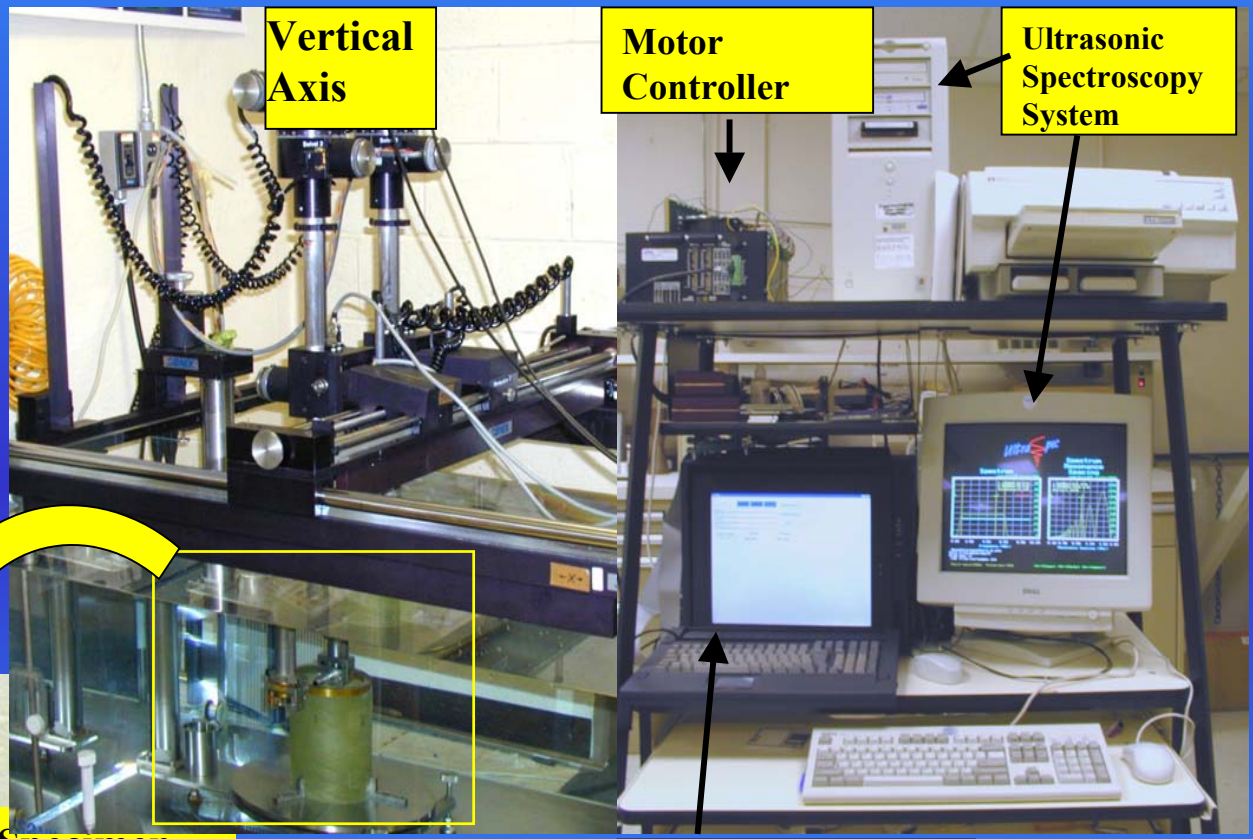


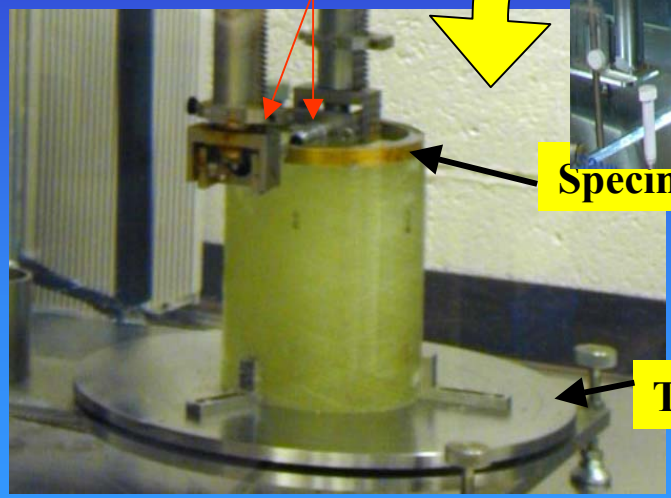
- No significant changes in the spectrum or spectrum resonance spacing domains, as expected

Glenn Research Center

The New Scanning Ultrasonic Spectroscopy System

UT - CEM





Scanning Ultrasonic Spectroscopy Results for Plexiglas Specimen

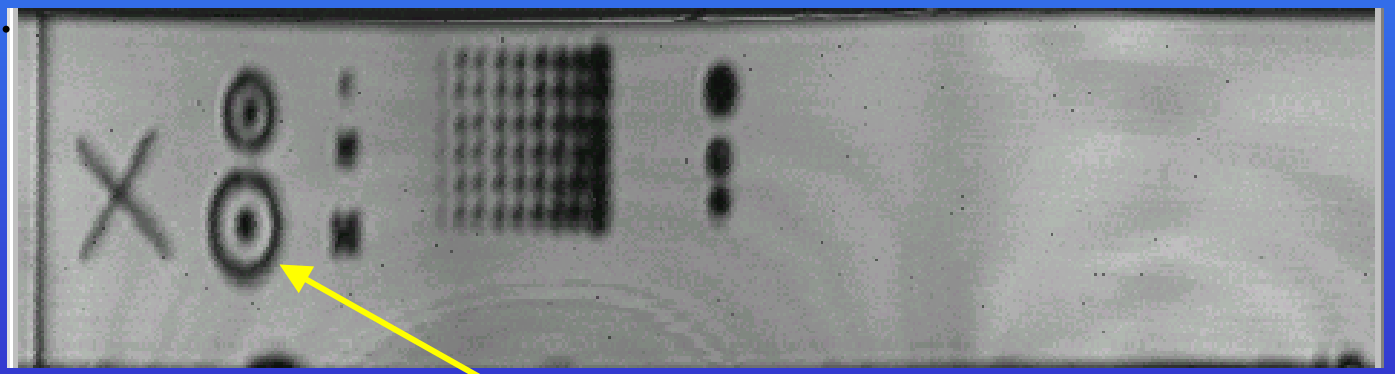
Glenn Research Center

UT - CEM

112mm.

Height

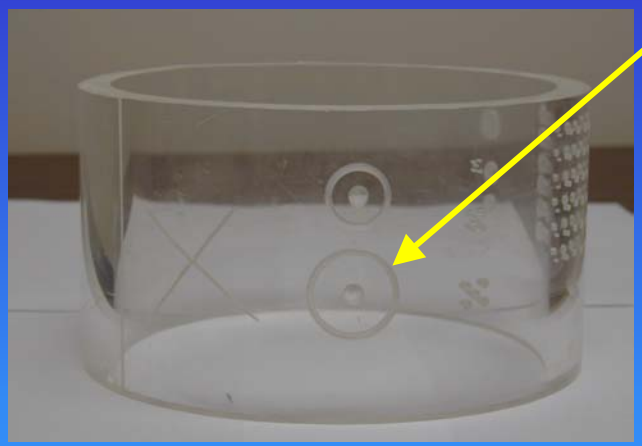
0



0º

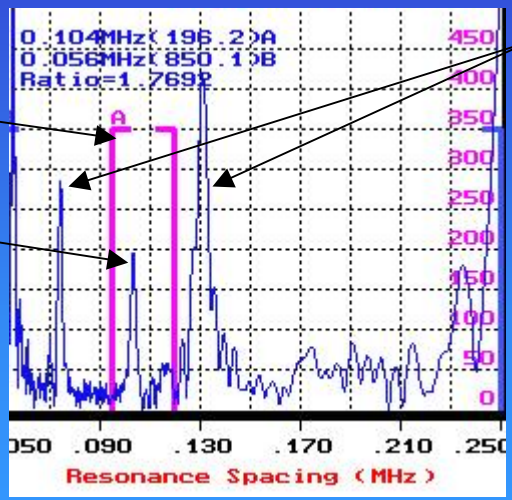
359º

Amplitude Decrease in Flawed Regions



Gated region for data collection

Full thickness resonance peak

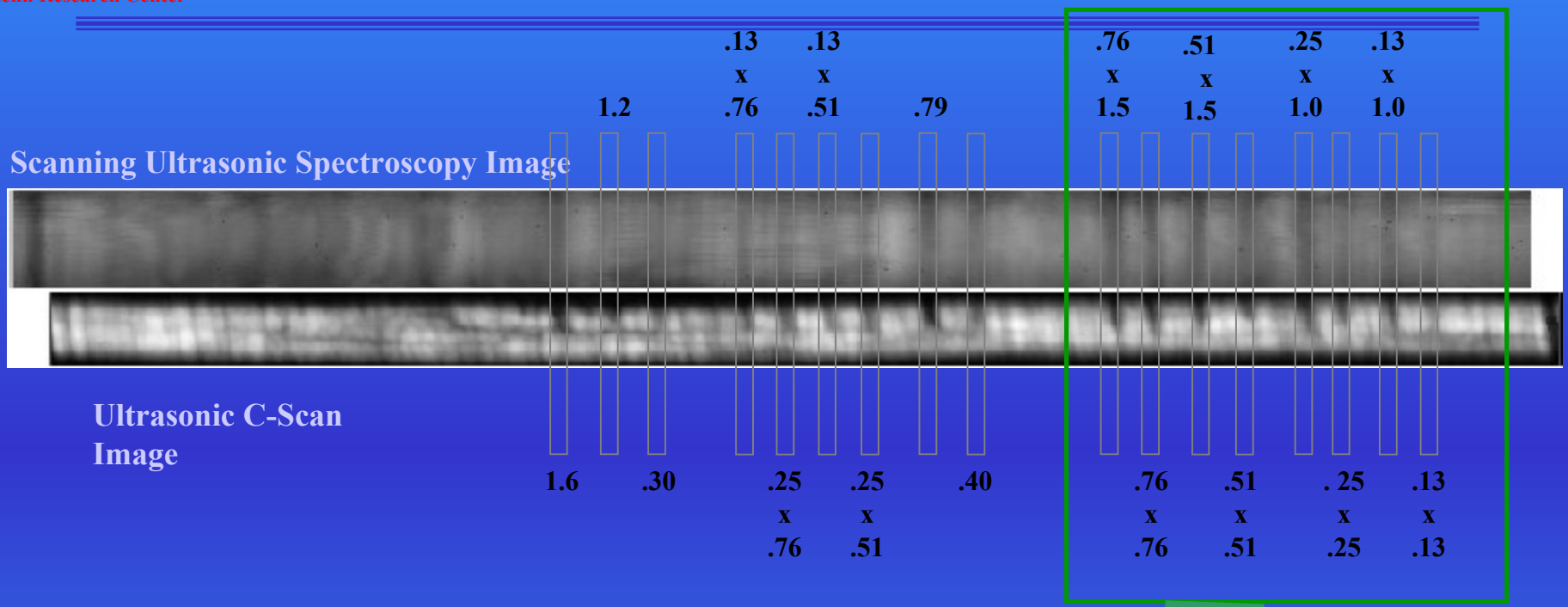


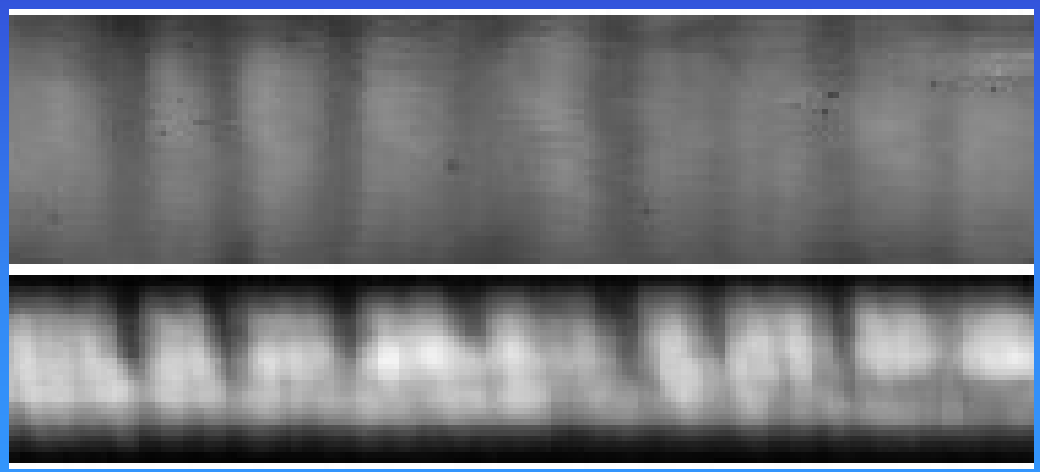
Resonant spacing peaks from water path

Scanning Ultrasonic Spectroscopy and C-Scan Results for NDE Ring Standard

Glenn Research Center

UT - CEM





Conclusions

- Established the capability of NDE imaging modalities in detecting critical flaws needed for composite rims certification
- Demonstrated the capability of material characterization NDE methods, like acousto-ultrasonics (earlier work) and ultrasonic resonance spectroscopy (herein), in gauging material degradation in composite rims and confirming successful manufacturing and/or proof testing
- Developed a new scanning ultrasonic resonance spectroscopy system for automated and fast NDE of composite rims