Nondestructive Evaluation Methods for the Ares I Common Bulkhead

Abstract:

A large scale bonding demonstration test article was fabricated to prove out manufacturing techniques for the current design of the NASA Ares I Upper Stage common bulkhead. The common bulkhead serves as the single interface between the liquid hydrogen and liquid oxygen portions of the Upper Stage propellant tank. The bulkhead consists of spin-formed aluminum domes friction stir welded to Y-rings and bonded to a perforated phenolic honeycomb core. Nondestructive evaluation methods are being developed for assessing core integrity and the core-to-dome bond line of the common bulkhead. Detection of manufacturing defects such as delaminations between the core and face sheets as well as service life defects such as crushed or sheared core resulting from impact loading are all of interest. The focus of this work will be on the application of thermographic, shearographic, and phased array ultrasonic methods to the bonding demonstration article as well as various smaller test panels featuring design specific defect types and geometric features.

Keywords:
Composite materials, NDE, Cryogenic structures

--Presenting Author--
James Walker
NASA MSFC
EM20
Bldg 4711 Rm W114
MSFC AL 35812
USA
256-961-1784
james.l.walker@nasa.gov

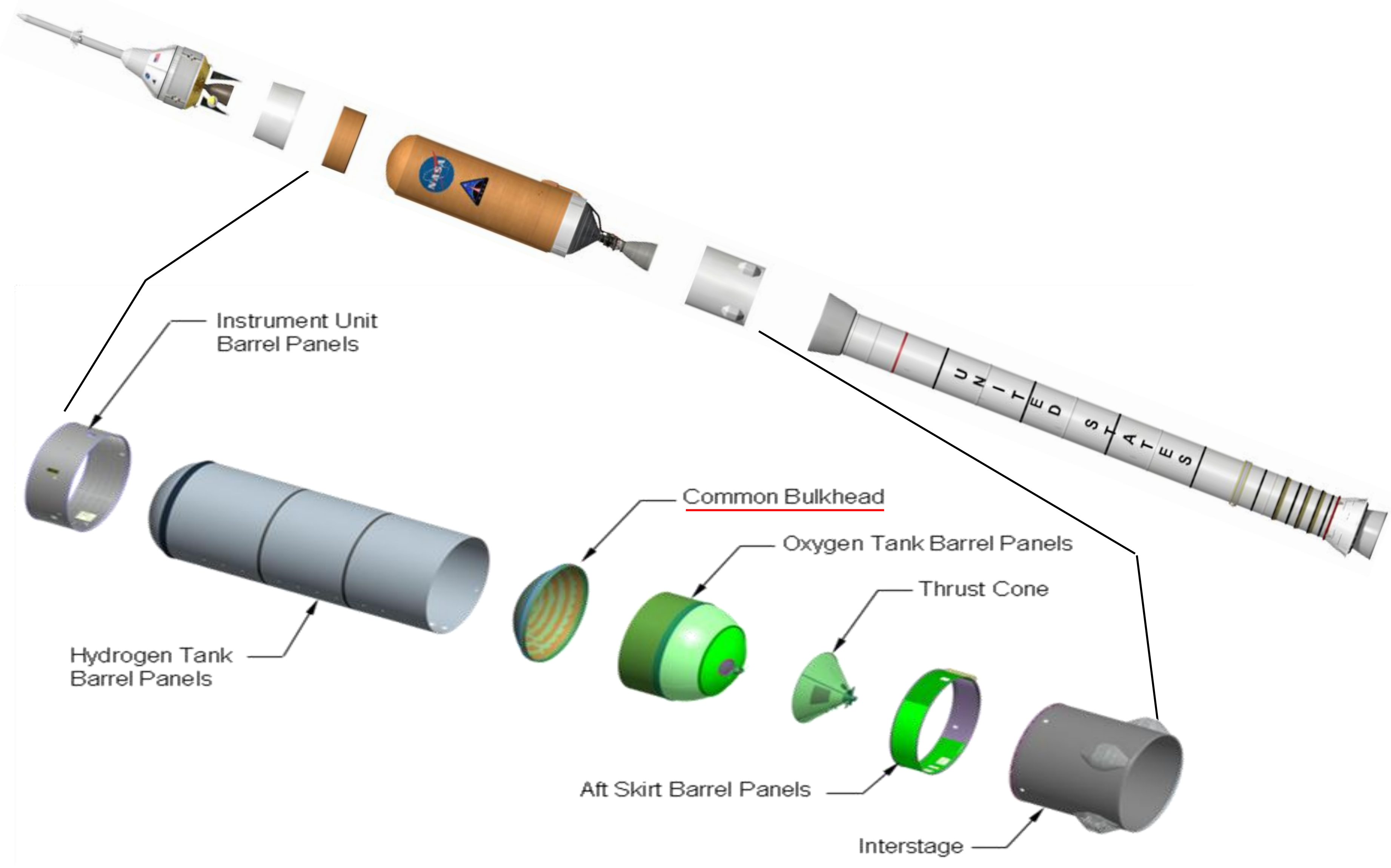
National Aeronautics and Space Administration

Nondestructive Evaluation Methods for the Ares I Common Bulkhead

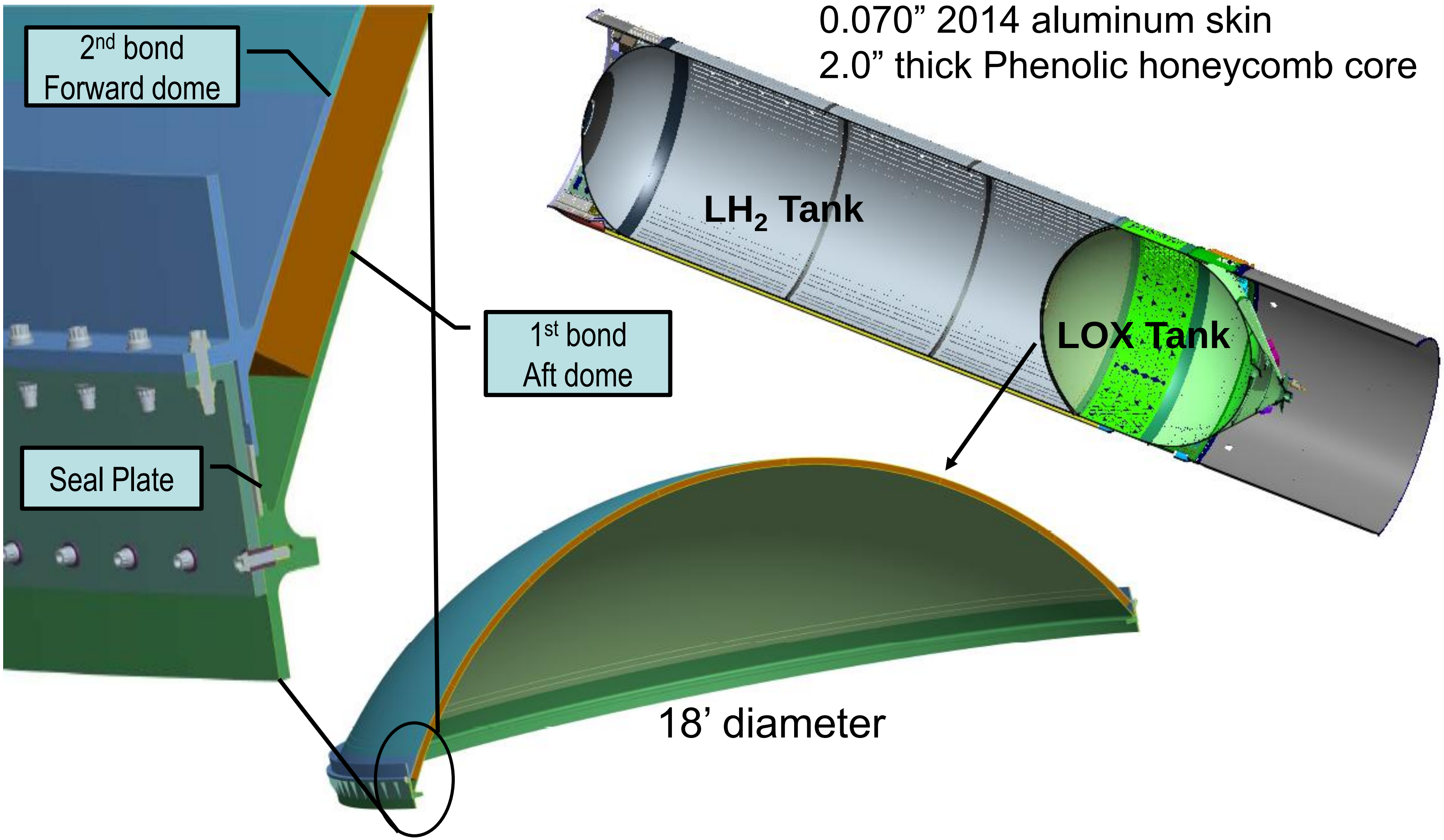
James Walker
NASA
Marshall Space Flight Center

ASNT Spring Conference
March 24, 2010

ARES I UPPER STAGE

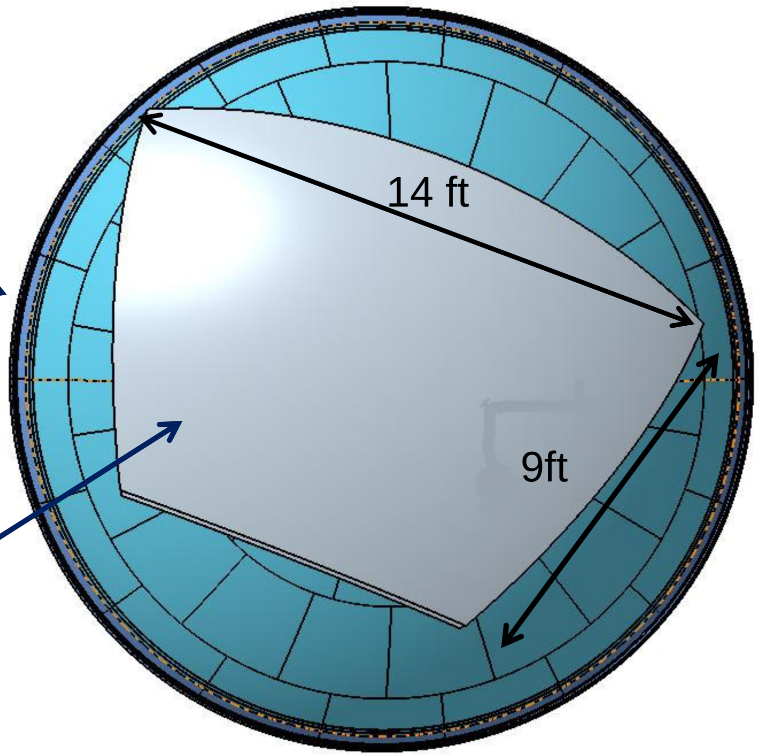


ARES 1 UPPER STAGE COMMON BULKHEAD

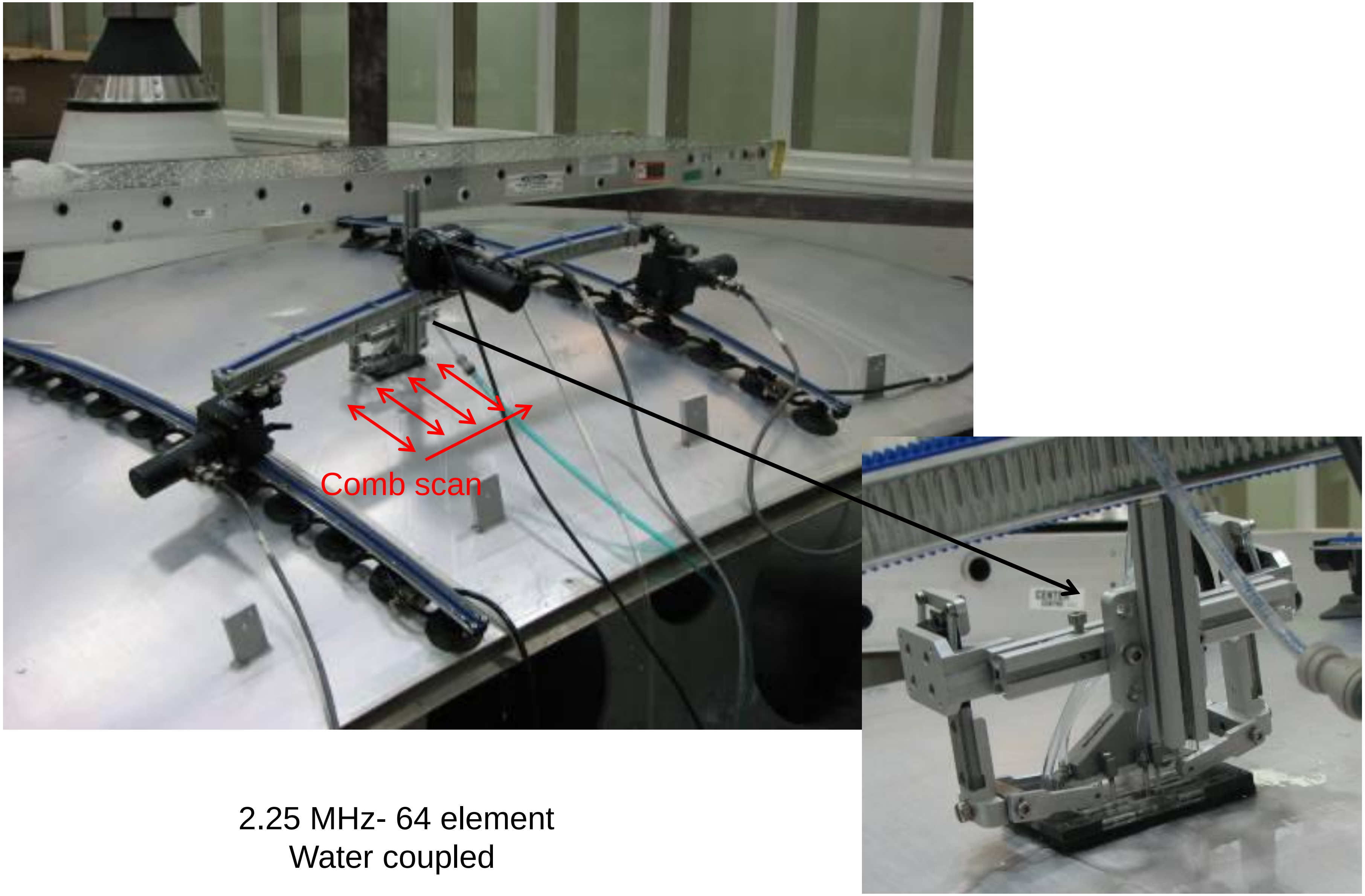


- PAUT is being developed to be used for 1st and 2nd bond prior to installing seal plate
- Shearography is being developed to be used after installing seal plate, pre and post proof test

Bonding Demonstrator

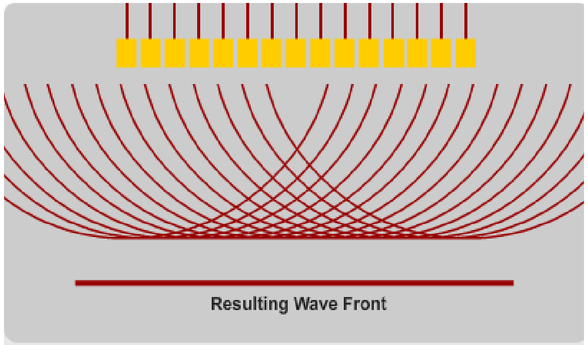


Phased Array Ultrasonics (PAUT)

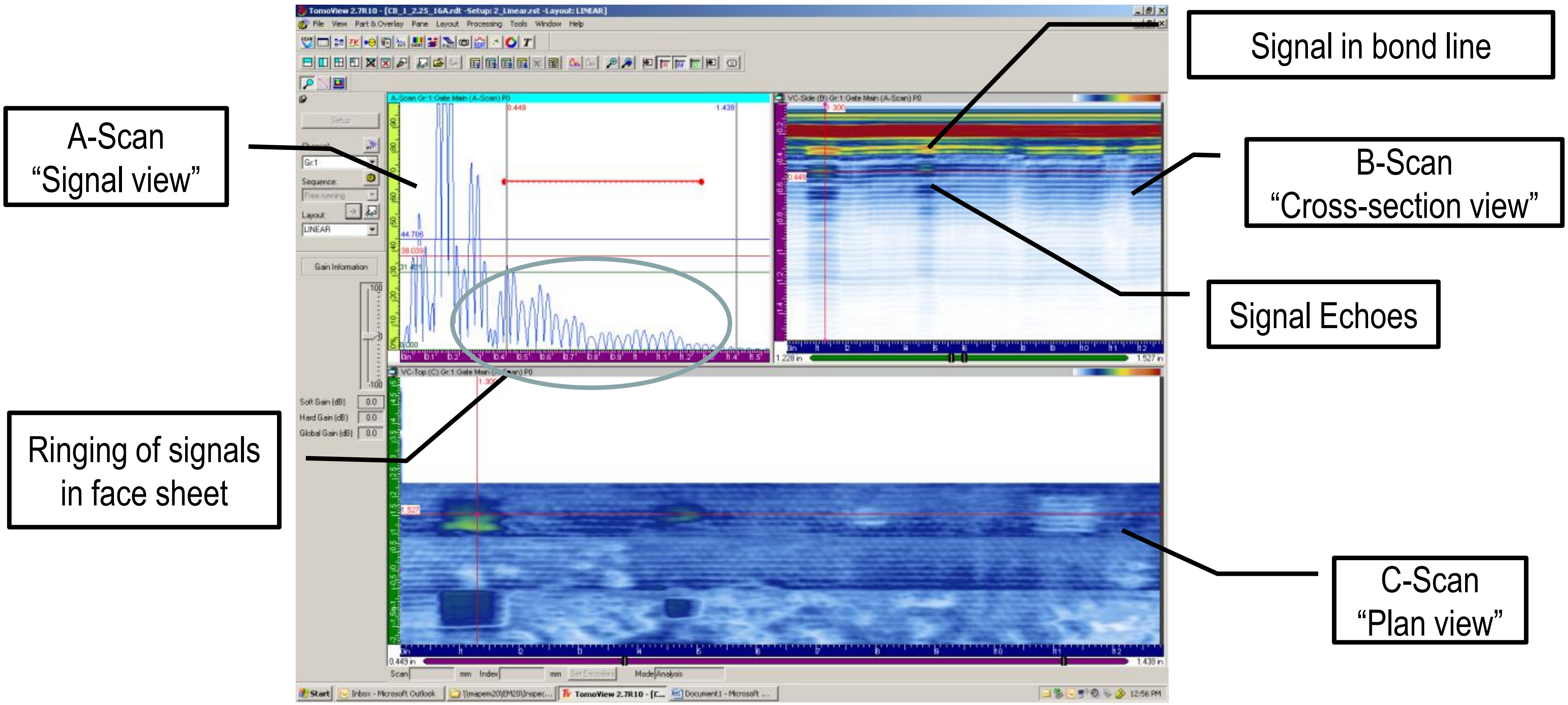


2.25 MHz- 64 element
Water coupled

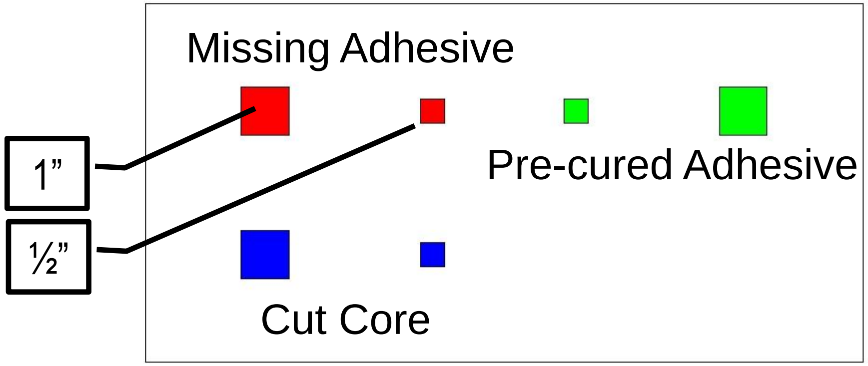
How to Interpret the PAUT Images



- System tuned to look for “ringing” of the signal and amplitude changes as the result of a lack of bond
- 16 element aperture (16 elements fired at a time rastered across the 64 element array in 1 element steps)
- 2.25 MHz
- A-scan image from location of cross-hairs in C-Scan
- Water coupled

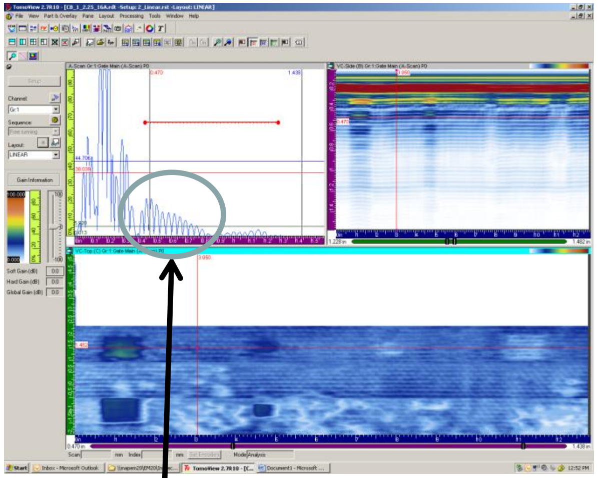


Phased Array Ultrasonics

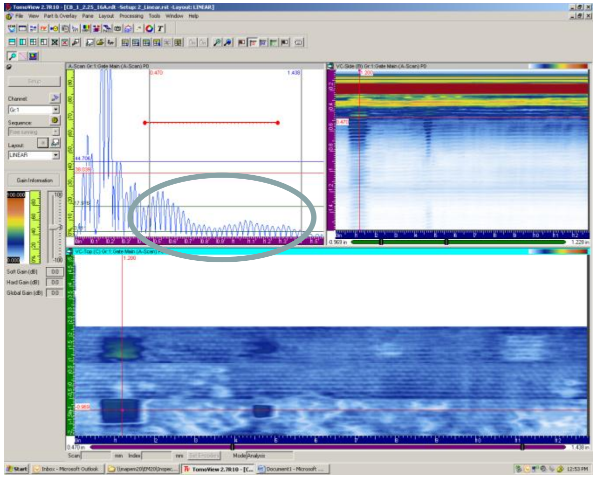


Calibration Standard

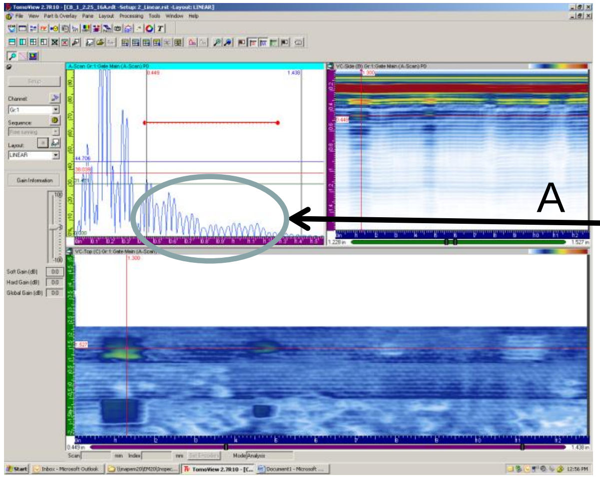
A. Increased ringing duration and amplitude for the cut core and missing adhesive defects over no defect regions
B. The ringing portion of the signal changes in time and amplitude for no defect over pre-cured adhesive defect



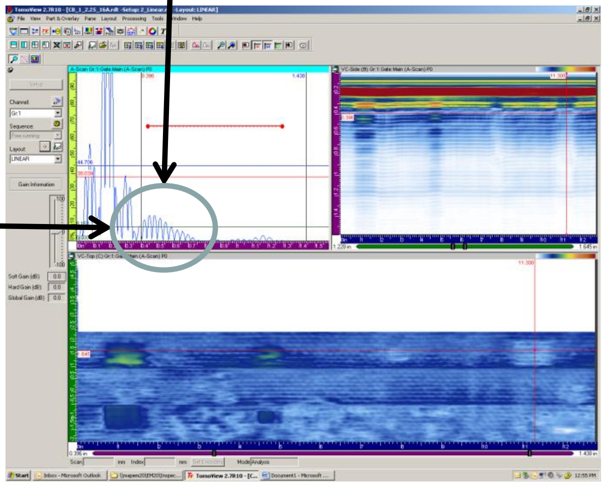
No Defect



Cut Core

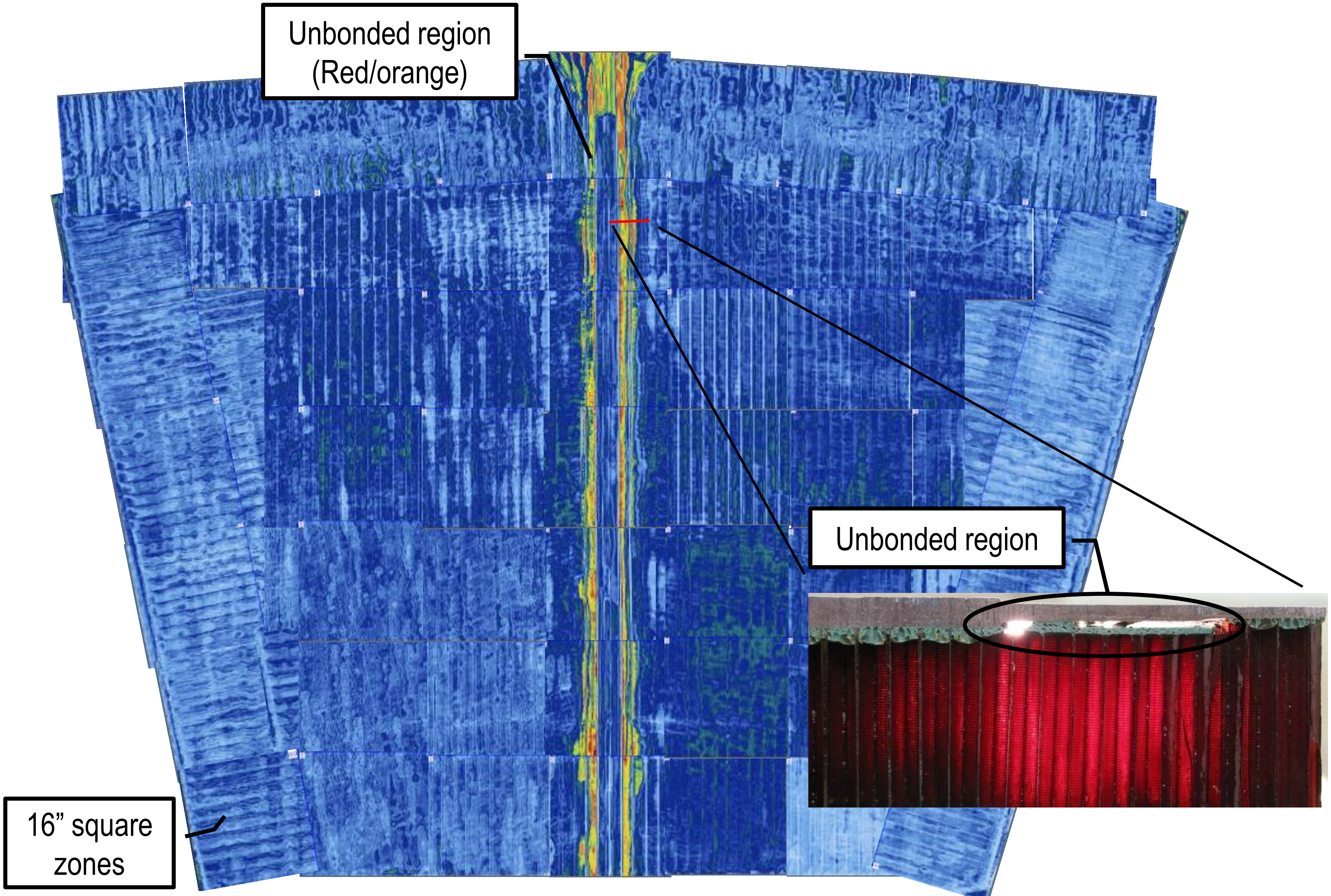


Missing Adhesive



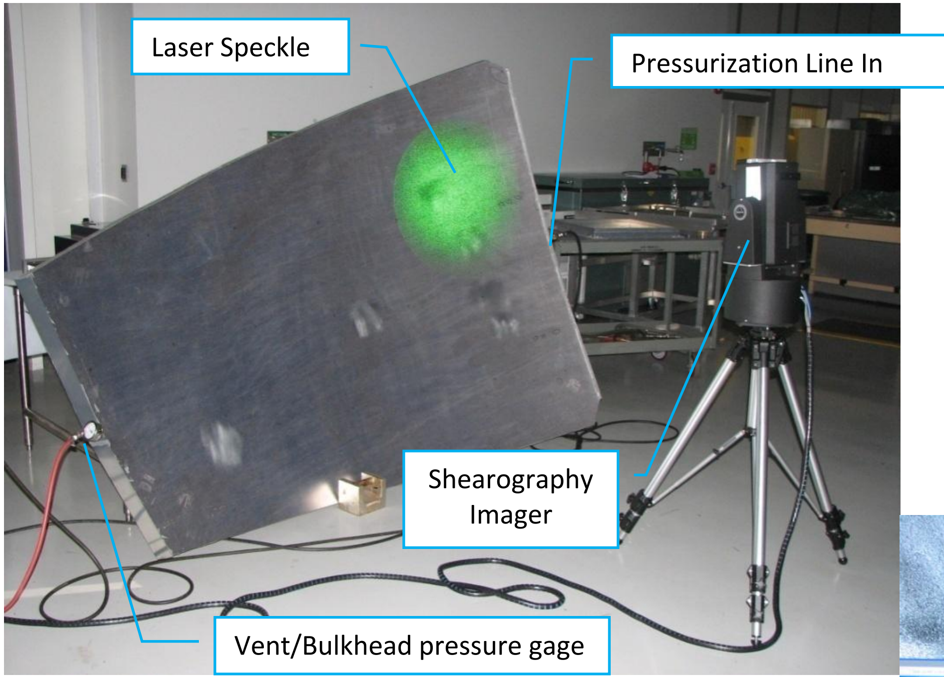
Pre-cured Adhesive

Phased Array Ultrasonics



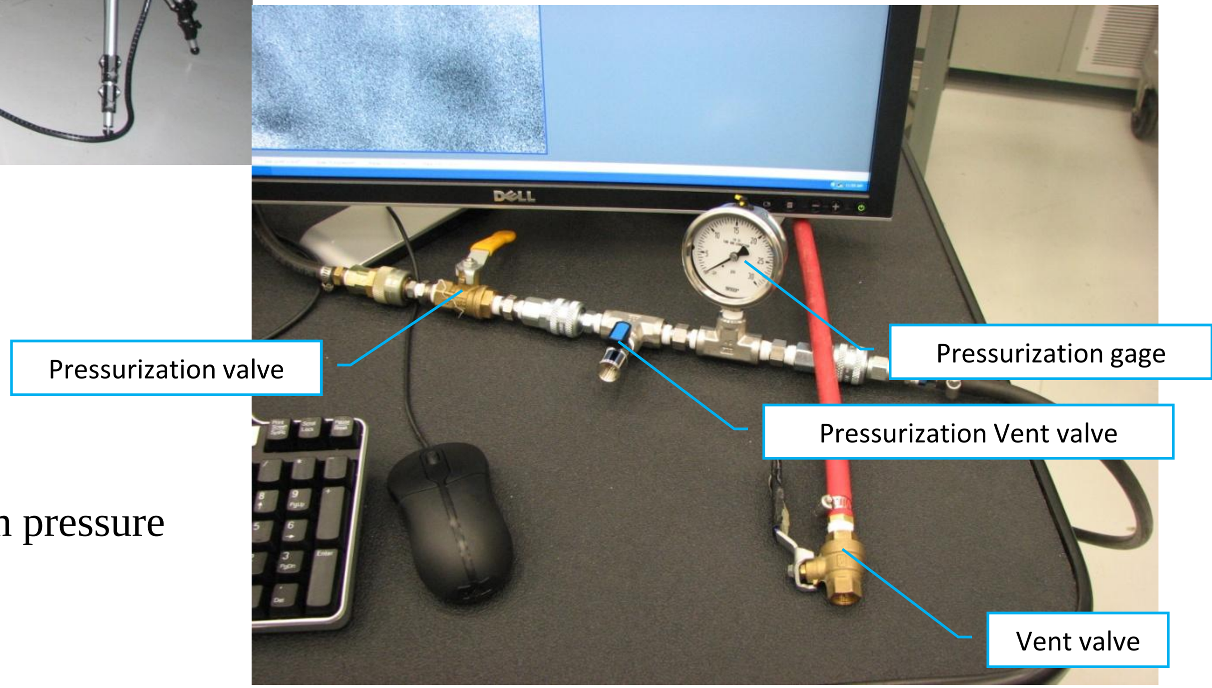
PAUT Mosaic of 2nd bond side (forward dome)

Shearography



Nominal settings

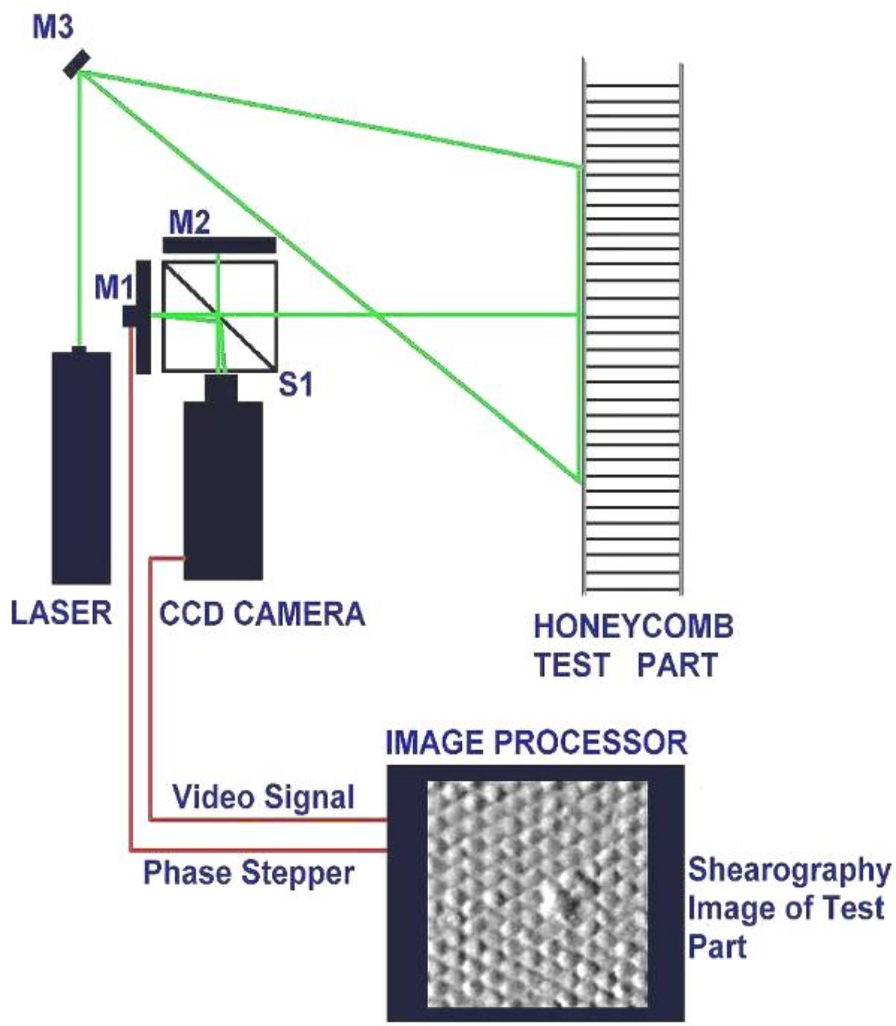
- Shearography Camera: LTI-5100HD
- Excitation: 1.5 to 2 psig internal pressure
- Field of view: 16” x 16”
- Surface Prep: None



Alternative settings tested

- Excitation: -5 in hg (-2.5 psig) vacuum pressure
- Field of view: 24” x 24”, 32” x 32”

How Shearography Works



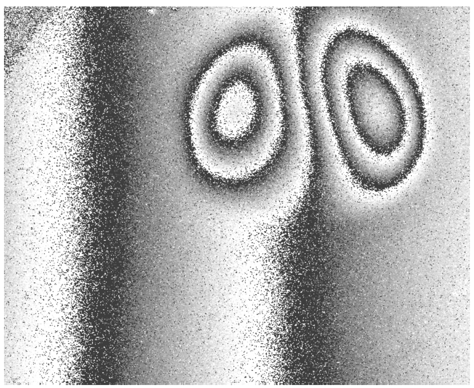
532 nm laser => Frequency doubled Nd:YAG
(Neodymium-doped Yttrium Aluminium Garnet)

- Uses a "laterally sheared" laser interferometer to compare the positions of adjacent points on the surface of a test article
- Provides a "map" of "relative" out-of-plane displacements between adjacent points on the test article
- Directly related to the first derivative of changes in target surface profile when a change in stress is applied
- The "shear vector" controls the direction and magnitude of maximum sensitivity
- Sensitive to changes in target surface profile to about 50 nm ($\lambda/10$)

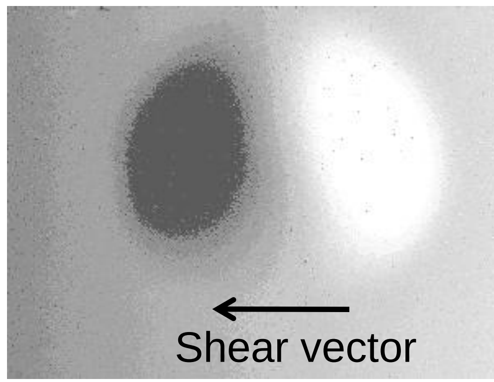
- Real-Time imaging of subsurface defects
- Non-Contact
- Non-contaminating

How Shearography Works

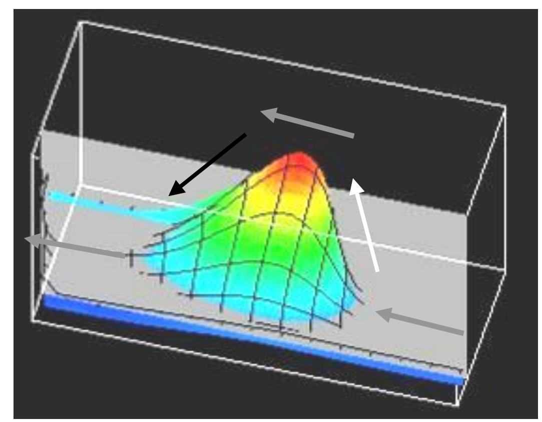
- Image of a indication yields a two lobed, light-dark, pattern
- Wrapped phase map image shows individual fringes corresponding to integer amounts of motion related to the wavelength of the laser illumination
- Unwrapped phase map stacks those integer amounts of motion on one another to give a summation of motion for each lobe
- The lobes are the result of the surface slope changing from zero (no fringe), to positive (white to black fringes or white summation), to zero at the peak of the defect deflection, to negative (black to white or black summation, and then back to zero as you step off the defect



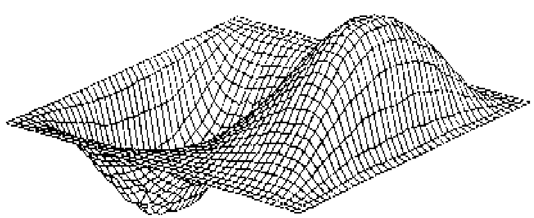
Wrapped Phase Map



Unwrapped Phase Map



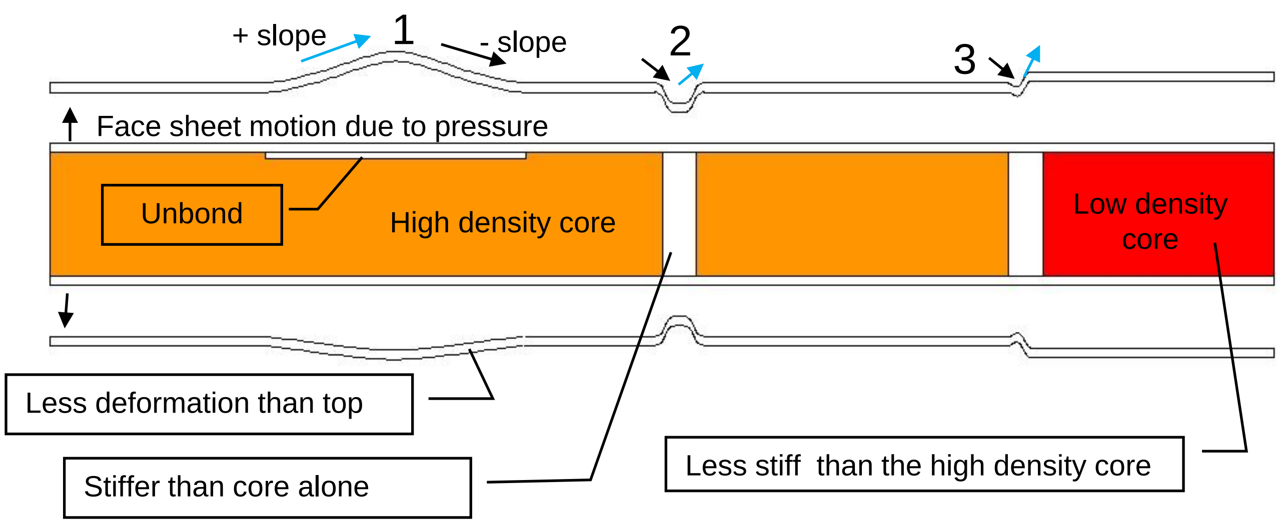
Displacement profile

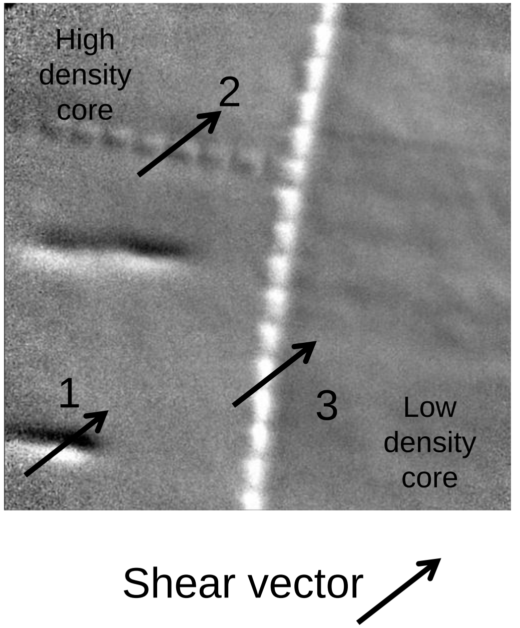


Contour map of slope changes

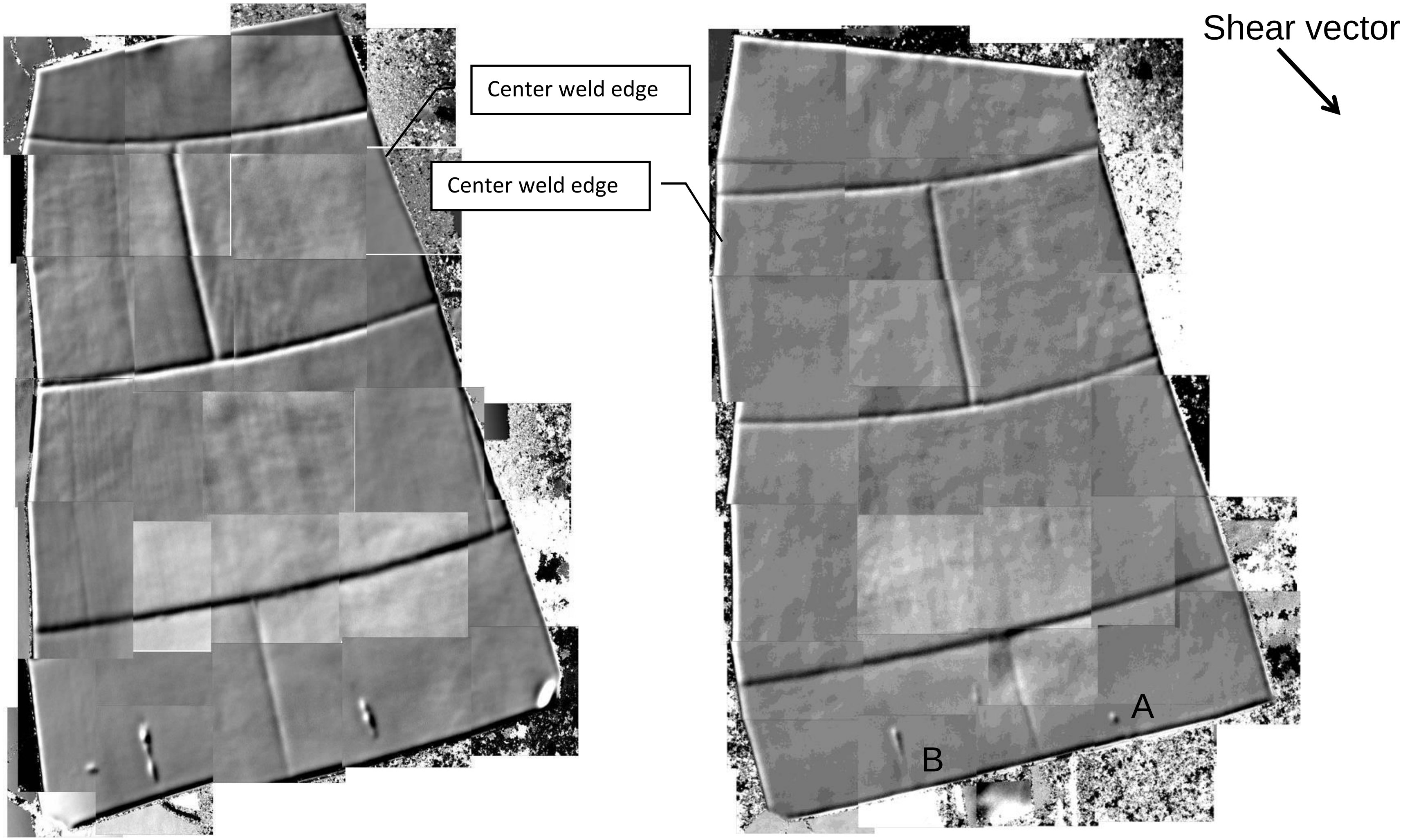
How to Interpret the Shearography Images

- **Stressing => Positive internal pressure**
- **Moving in the direction of shear**
  - **(1) White to black indication => Indication moving outward relative to its surrounding (Less stiff, indicating weak bond, unbond or core defect)**
  - **(2) Black to white signature => Indication moving inward relative to its surrounding (added stiffness, the splice compound adds stiffness to the core)**
  - **Single color stripe**
    - **(3) White => The case where the shear vector crosses from the high to low density core overpowering the effect of the core splice to deflect inward**
    - **Black => The case where the shear vector crosses from the low to high density core overpowering the effect of the core splice**



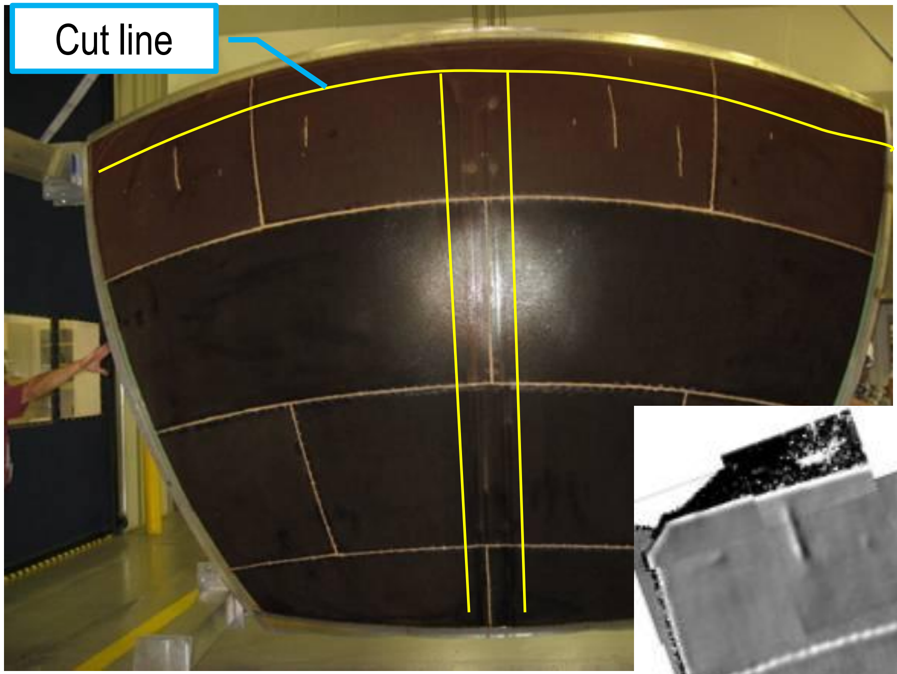


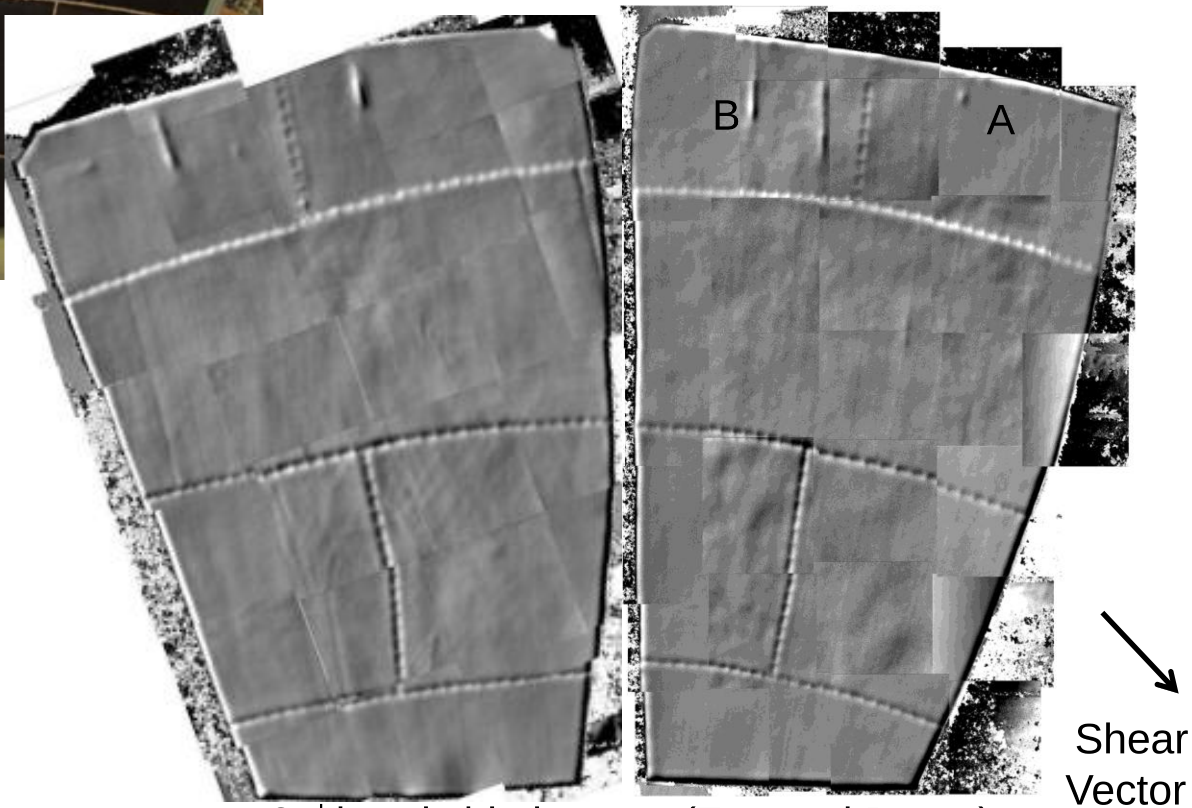
Overview of Indications



1st bond side images (Aft dome)

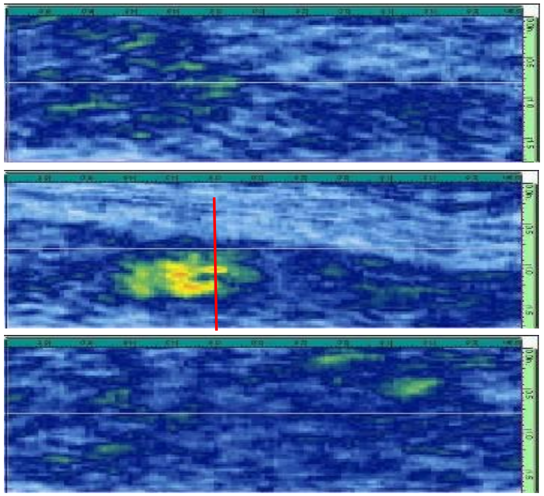
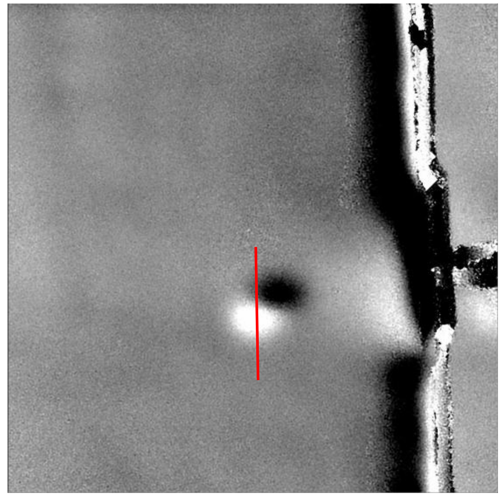
Overview of Indications (Comparison to Pre-bond Photo)



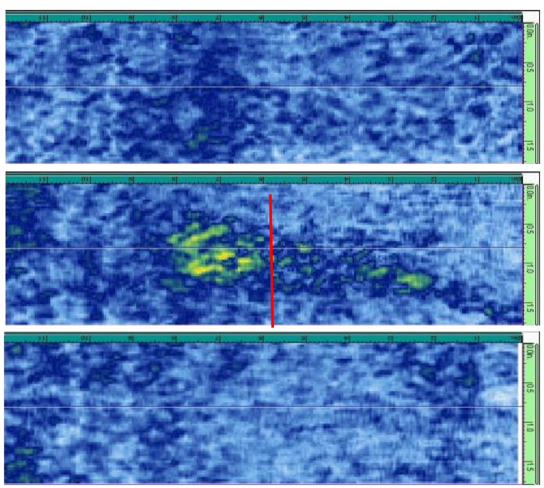
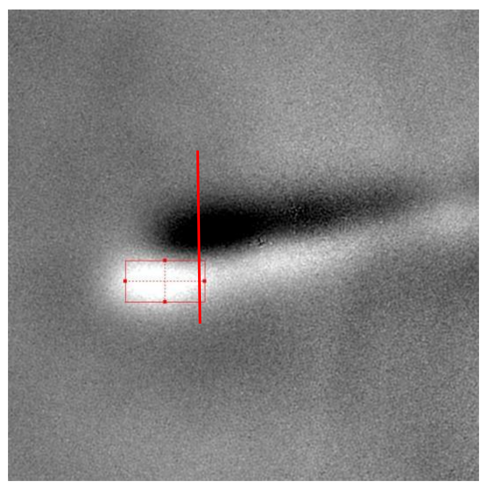


2nd bond side images (Forward Dome)

Comparison of Ultrasonics to Shearography

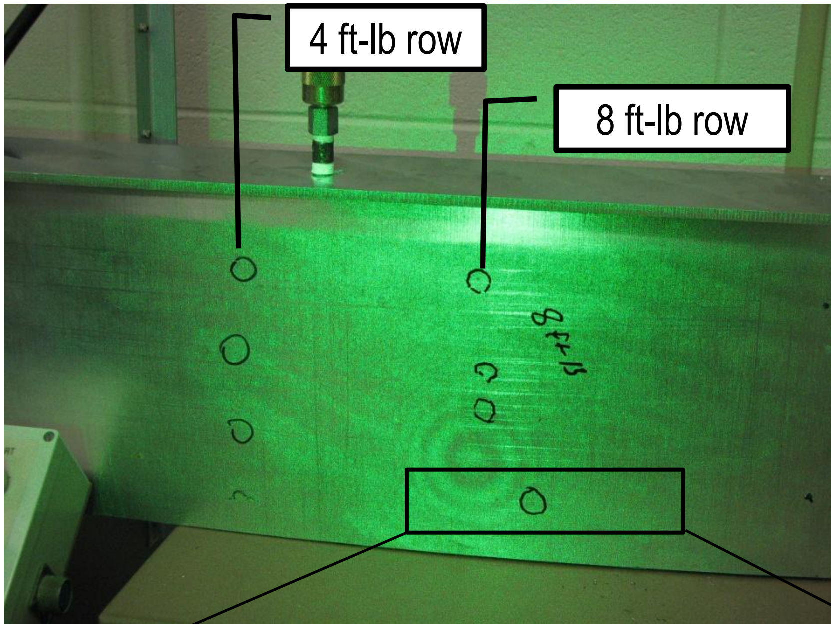
Phased Array Ultrasound	Shearography	Dissection
		

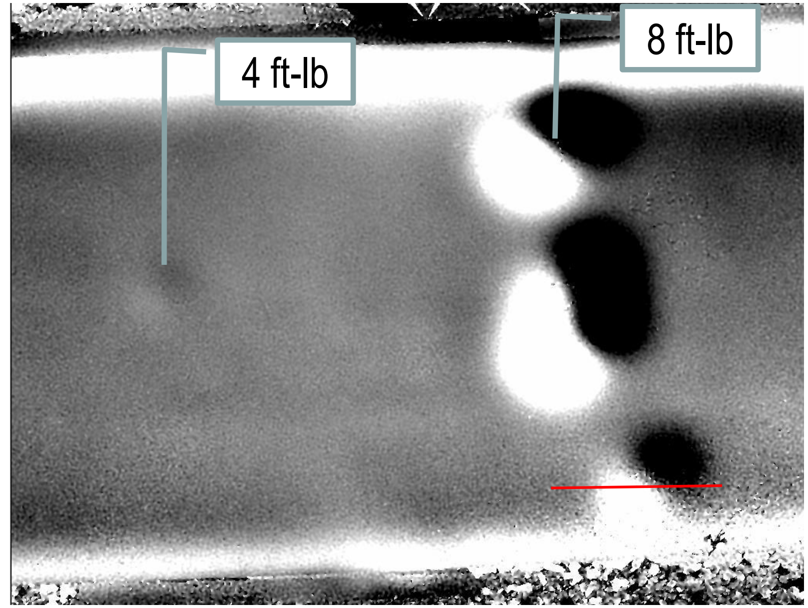
Indication A (1st bond side, aft Dome)

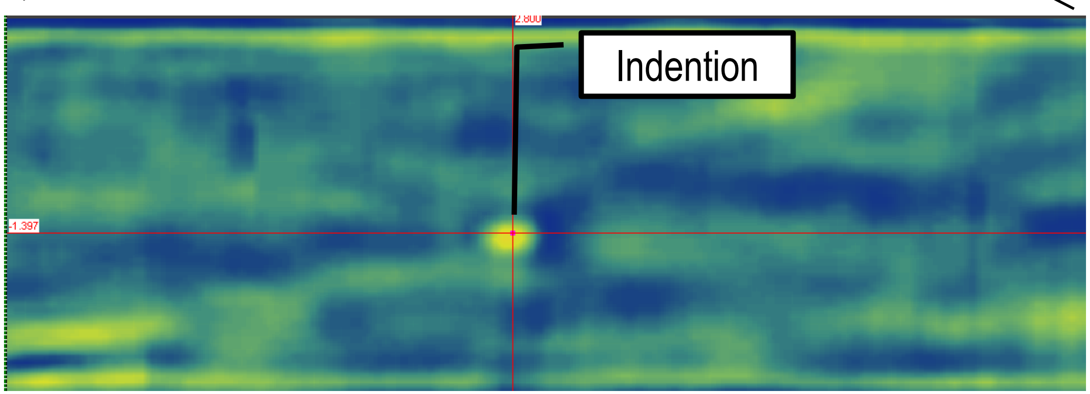
Indication B (1st bond side, Aft Dome)

Impact Damage Detection

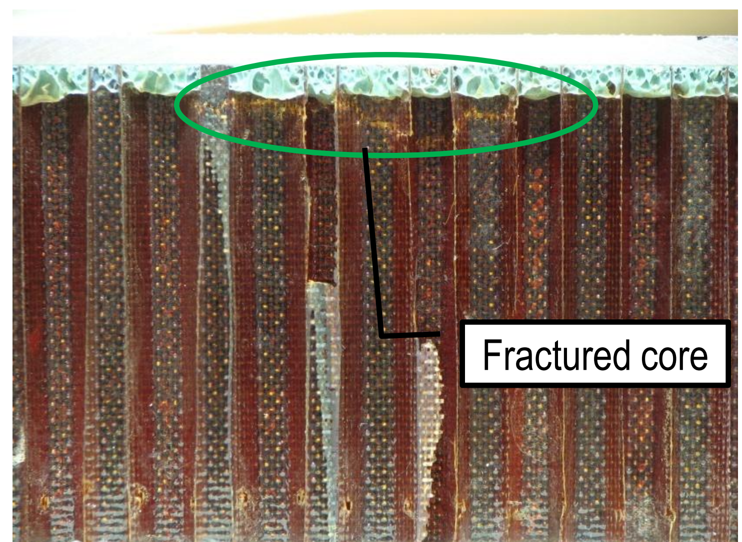




Pressure shearography (2 psi internal)



PAUT 2.25 MHz



Back-up charts

Displacement of an unbond

$$w = (P * a^4)/(64 * D) \text{ where } D = (E * t^3)/12 * (1-\upsilon^2)$$

(Circular disk under uniform pressure with fixed edges)

w = maximum displacement
P = pressure = 1 psi
a = radius = 0.5” (1” diameter debond)
E = Modulus of elasticity = $10(10^6)$ psi
t = thickness = 0.070”
υ = Poisson’s ratio = 0.3

$w = 3.109\ (10^{-6})$ inch [79 nm]

Laser wavelength “λ” = 532 nm

Can easily detect down to $\lambda/10$ => 53.2 nm (About 1.5 fringes)

At 2 psi w = 158 nm => About three fringes