Integrating Nondestructive Evaluation (NDE) into Modern Manufacturing

David Forsyth

SME Composites Forum

19 – 20 July 2022

Wichita, KS

What is TRI Austin?

- One of 8 companies owned by Texas Research International, Inc.
- About 40 engineers, scientists, technicians, and support staff.
- 40 years of contract research and development in materials and materials testing for government and commercial clients.

From Dr. Russell

- I'm pleased to invite you to the Aerospace Composite Forum, produced by SME and NIAR and hosted by yours truly. The Forum will be July 18-20 at NIAR in Wichita KS. This is an invitation-only event to talk about what's going on in aerospace composites and what the next decade looks like for the industry.
- …
- This will be two days of presentations on technical subjects such as Next Generation Materials, Structural Design, Low-Cost Agile Manufacturing, Quality Assurance, Qualification and Certification, and Industry 4.0. In addition, there will be application-focused discussions on military aviation, commercial aviation, and Urban Air Mobility. The workshop will wrap up with a roundtable discussion, reviewing what was presented and reflecting on needs for future research.

Nondestructive evaluation (NDE)

How are we going to do this?

- Quick NDE refresher.
- NDE problems and possibilities.
- Digital transformation for NDE

Quick NDE Refresher

- If you are building composite structures for aerospace, it's ultrasonics with full coverage.
  - Pulse echo
  - Through transmission
    - Air coupled
- Can be delivered many ways.
  - probe, array probe on robot in squirter or immersion
  - roller probe, dry "camera", air coupled, laser…
- Thermography, shearography, tap test.

What can UT do?

- Echoes! Reflections from changes
  - FOD, delam, disbond
  - Porosity
  - Bonds
  - Layers in composite
- Time of flight ~ thickness, density, modulus

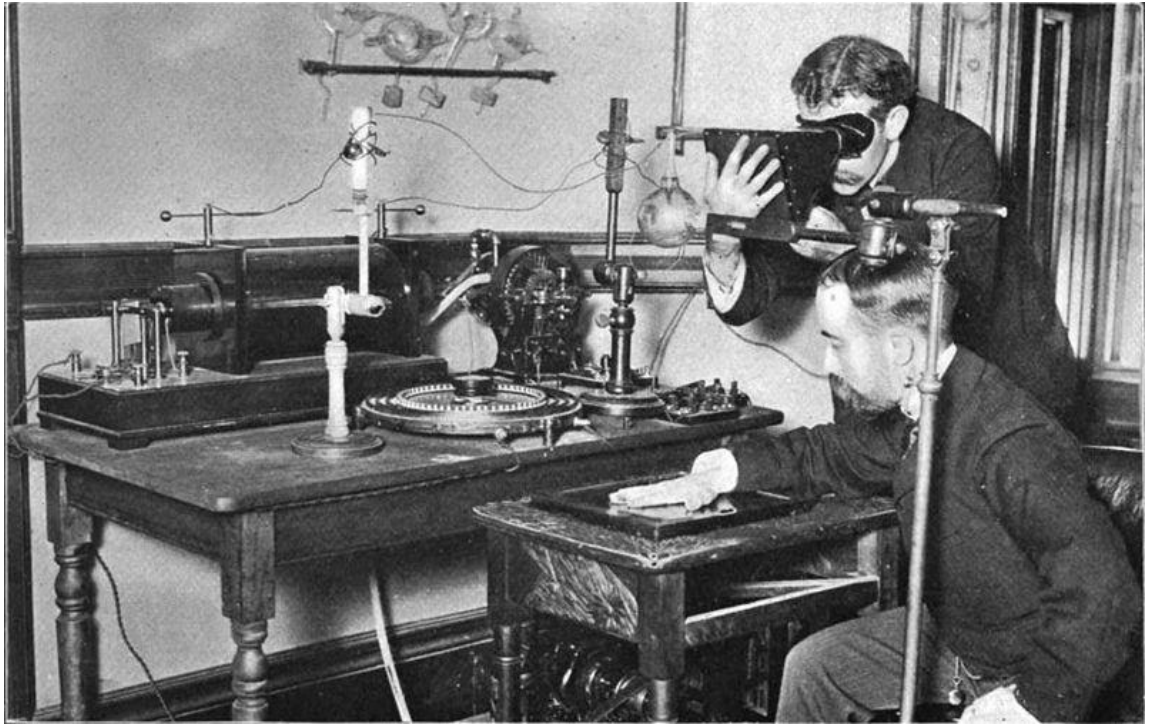
Robotically acquired UT

How are we going to do this?

- Quick NDE refresher.
- NDE problems and possibilities.
- Digital transformation for NDE.

Bonded composite aircraft

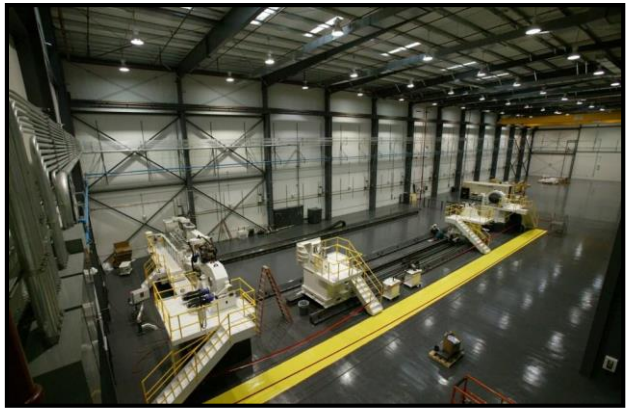
Image-based NDT

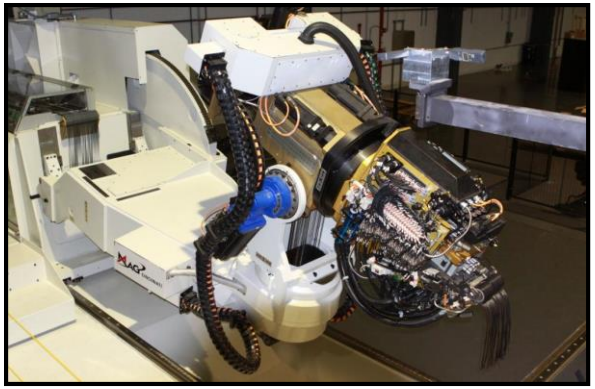


William J. Morton and Edwin W. Hammer (1896) The X-ray, or Photography of the Invisible and its value in Surgery, American Technical Book Co., New York, fig. 54

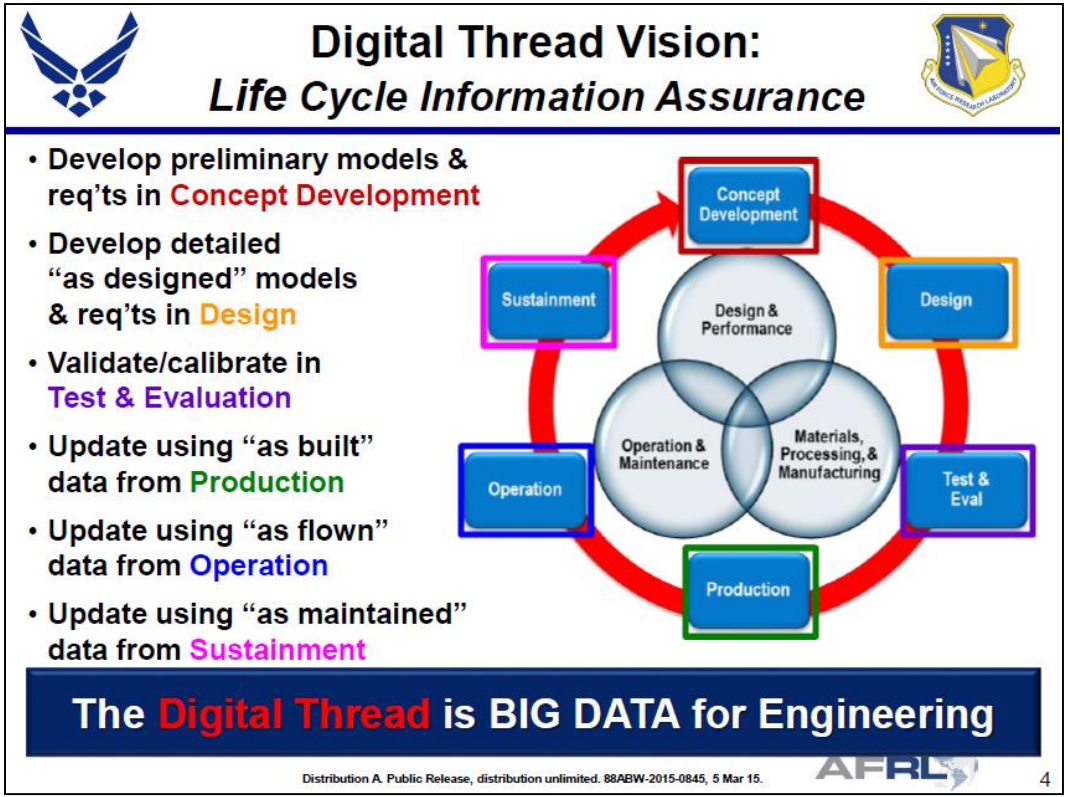
… and Now

Courtesy of HITCO CARBON COMPOSITES, INC



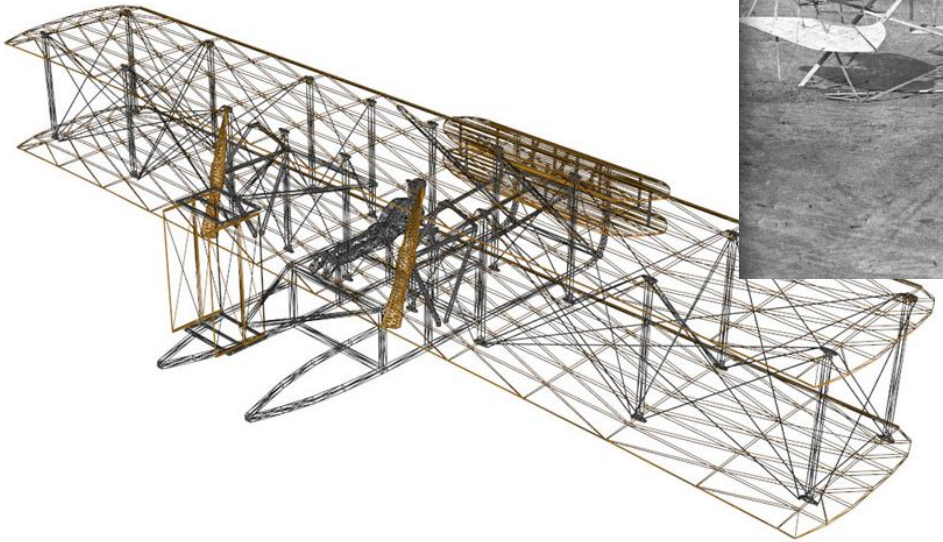


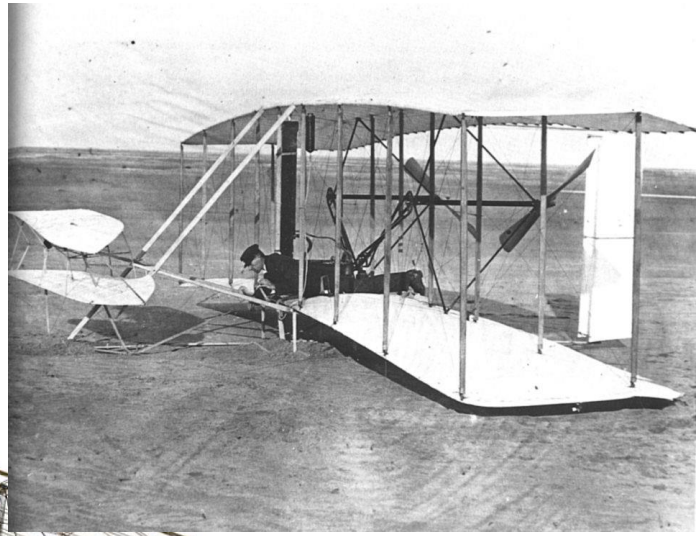
Digital Thread



Digital Thread

- We have digital plans…





Digital Thread

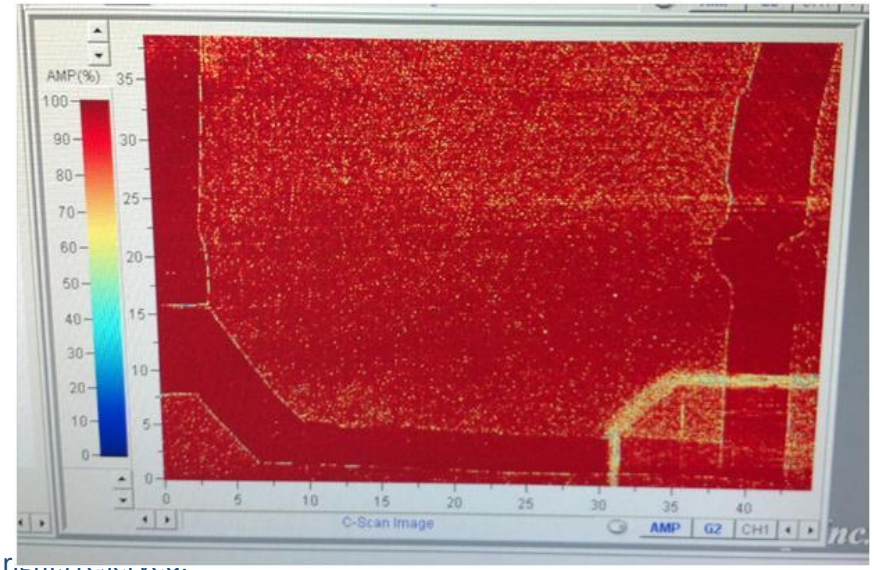
- We have machines that can build from digital plans…

Digital Thread

- We have inspection systems that provide digital data…

Digital Thread

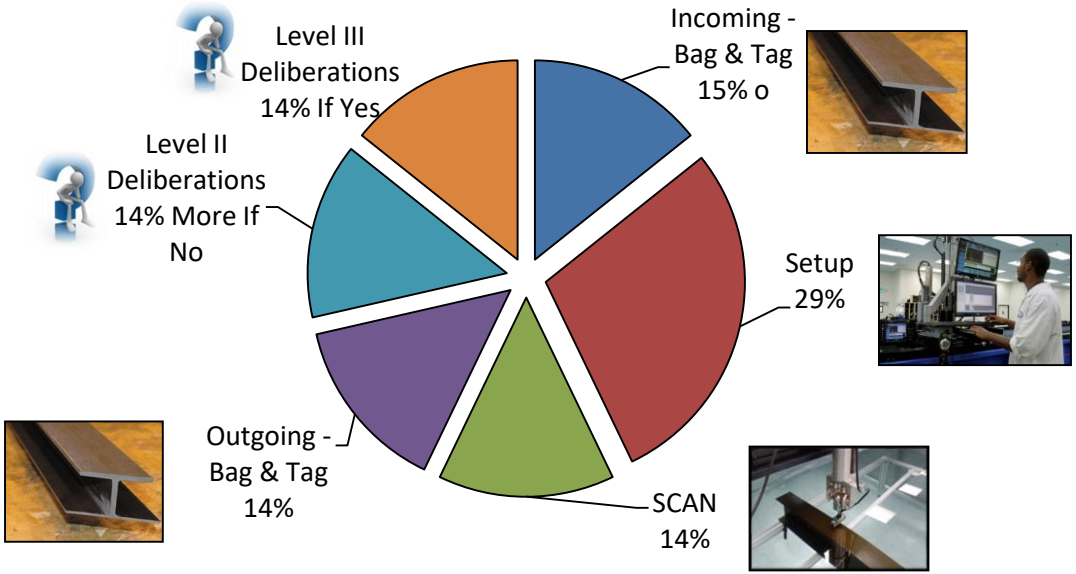
- Digital thread right up to the point where we get digital NDT data like this…



Digital Thread stops at the Level III

C-Scan Processing Time

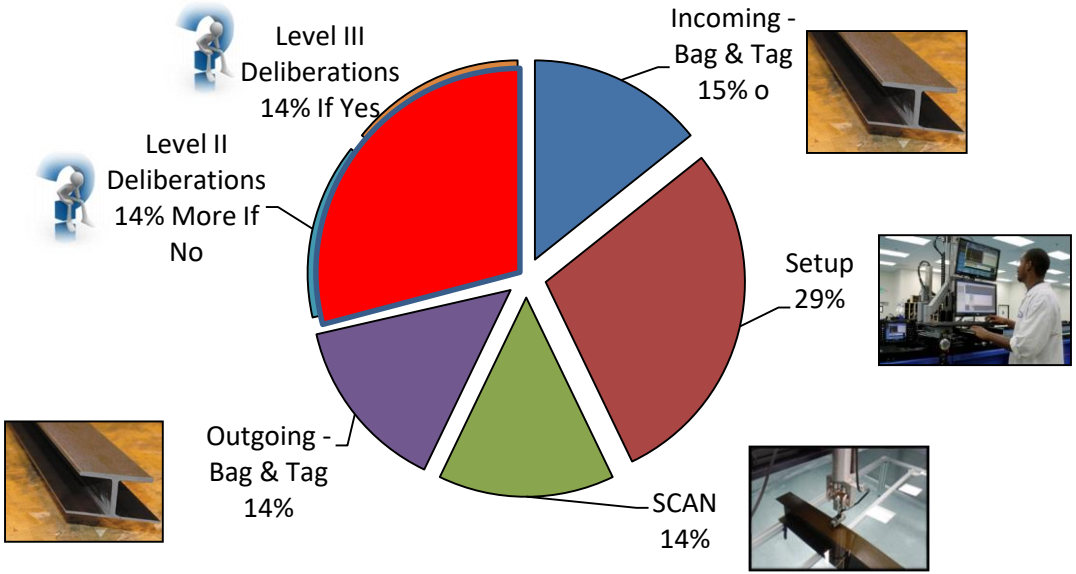
- 210 minutes
  - ✓ if Level II deliberations identify that a Beam meets part qualification criteria.
- 240 minutes if Level II deliberations identify that a Beam does not meet part qualification criteria.
  - ✓ This additional to validate deliberations basically scraps the part or puts it on hold..



Courtesy of HITCO CARBON COMPOSITES, INC

C-Scan Processing Time

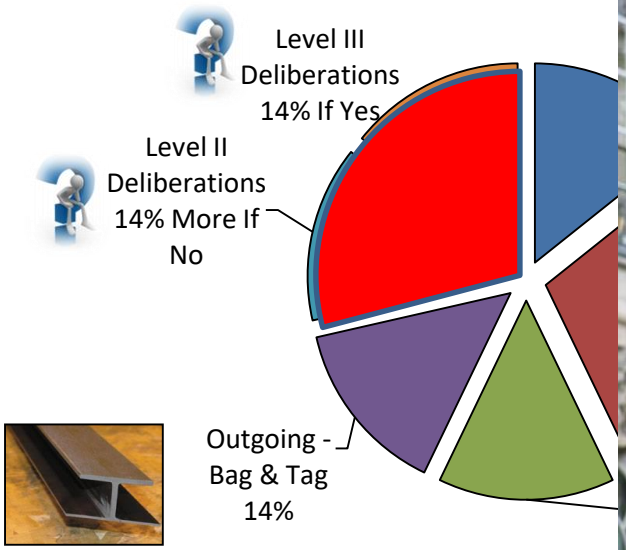
- 210 minutes
  - ✓ if Level II deliberations identify that a Beam meets part qualification criteria.
- 240 minutes if Level II deliberations identify that a Beam does not meet part qualification criteria.
  - ✓ This additional to validate deliberations basically scraps the part or puts it on hold..

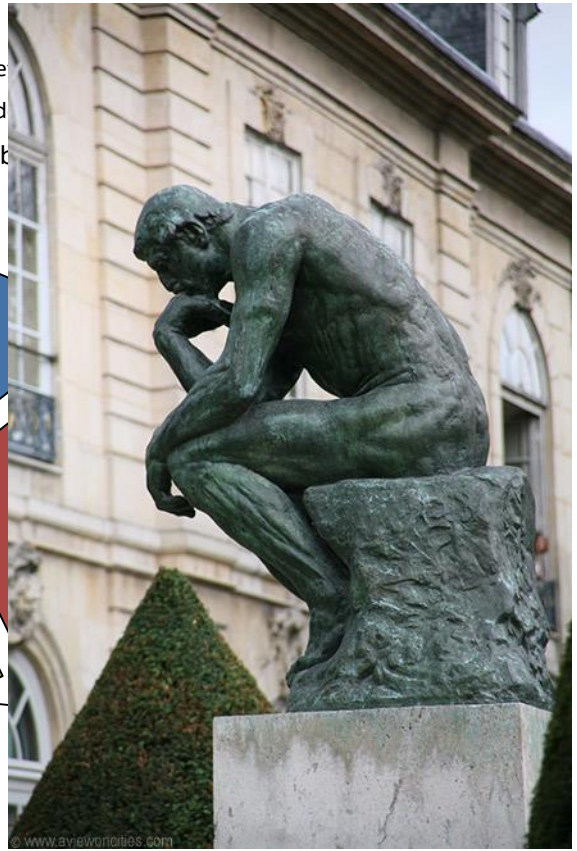


Courtesy of HITCO CARBON COMPOSITES, INC

C-Scan Processing Time

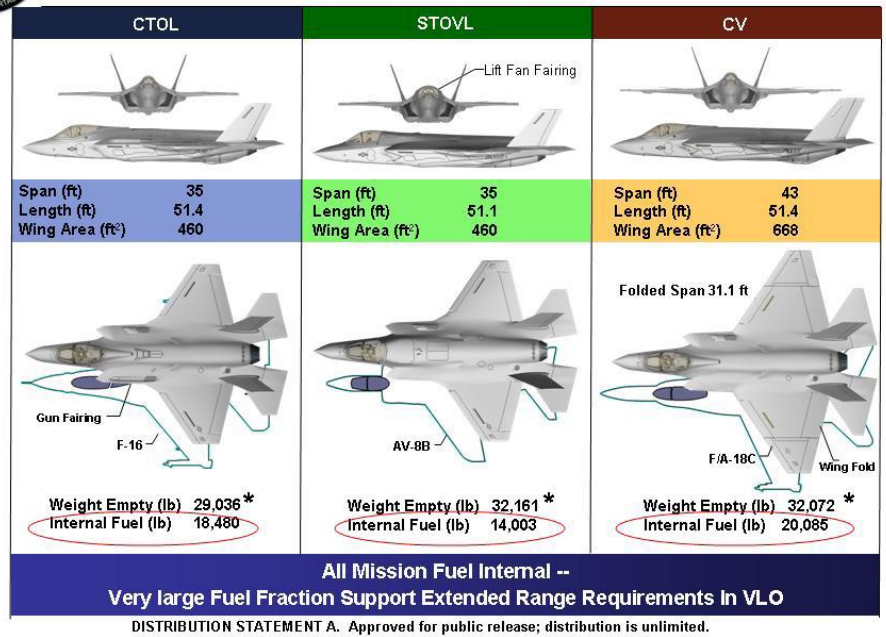
- 210 minutes
  - ✓ if Level II deliberations identify that a Beam mee
- 240 minutes if Level II deliberations identify that a Beam d
  - ✓ This additional to validate deliberations b





Courtesy of HITCO CARBON COMPOSITES, INC

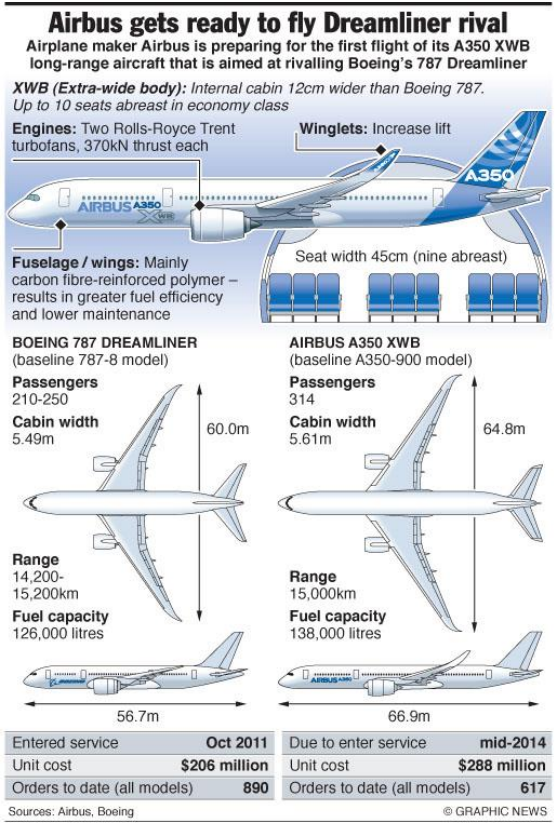
Too Much Data!



F-35 public information:

- 2mm scan spacing = 25 scan points per cm^2
- 668 ft^2 = 620,000 cm^2
- For each of upper and lower wing, evaluate 15 million A scans
- Add in some covers and empennage and etc.
- **Maybe 40 million ultrasonic signals**

Too Much Data!



- 2mm inspection spacing = 25 per cm^2
- Wing area approximately 5.4 x 10^6 cm^2
- For each of upper and lower wing, evaluate 135 million ultrasonic A scans
- Add in some covers and empennage and etc.
- **Maybe 300 million ultrasonic signals per aircraft**

Too much data.

- Inspectors only review a fraction, selected C scans out of the data set.
- Most of the data is good.
  - Large, monocoque structures are easy!
- So what does science tell us about this type of inspection situation?

Don’t set people up to fail!

HOME SEARCH

The New York Times

U.S.

Head of T.S.A. Out After Tests Reveal Flaws

By JADA F. SMITH JUNE 2, 2015

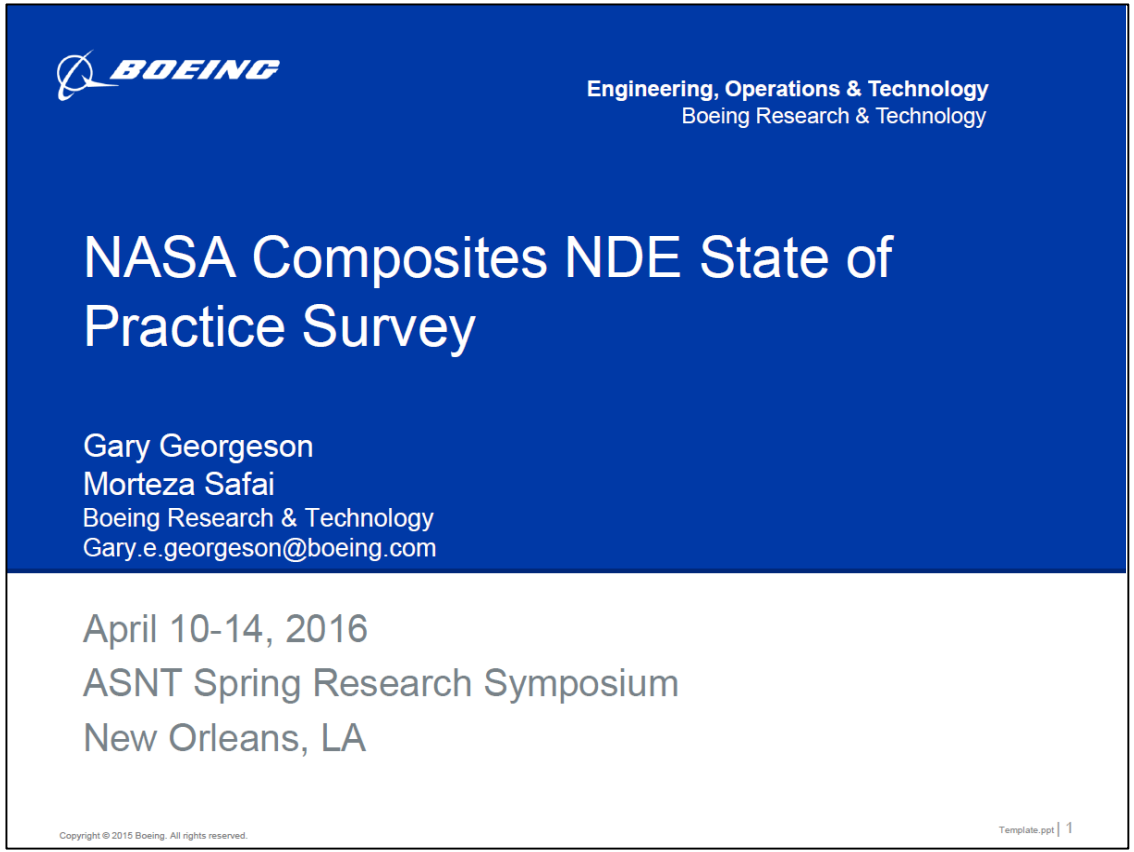
Email
Share
Tweet
Save
More

WASHINGTON — The Department of Homeland Security on Monday reassigned the acting director of the Transportation Security Administration and ordered the agency to revise its security procedures after screeners at airport checkpoints failed to detect weapons and other prohibited items 95 percent of the time in a covert test.

Jeh Johnson, the secretary of Homeland Security, which oversees the T.S.A., said that he took the findings of the investigation by the department’s inspector general “very seriously.” He called on the T.S.A. to retrain airport security officers, retest screening equipment and increase its use of covert testing in airports.

In the investigation, undercover agents were able to get prohibited items through security checkpoints in 67 of 70 instances, according to ABC News, which first reported the findings.

What does industry think?



BOEING

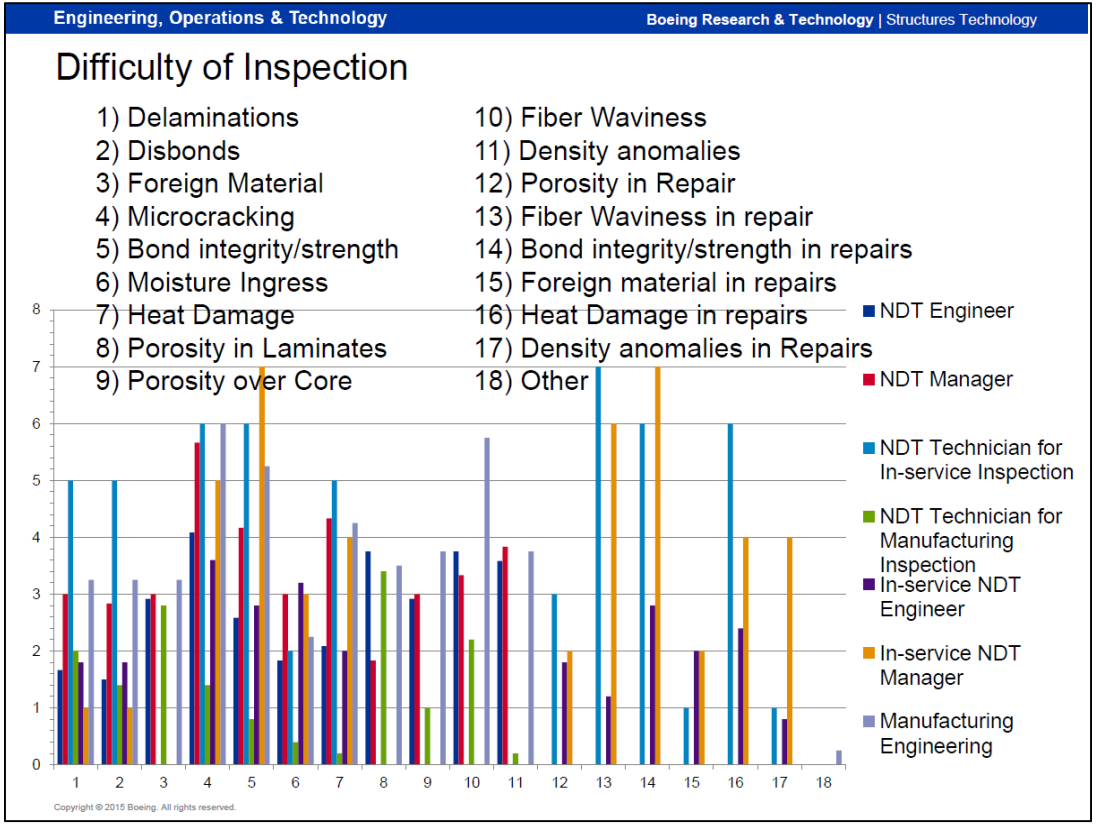
Engineering, Operations & Technology
Boeing Research & Technology

NASA Composites NDE State of Practice Survey

Gary Georgeson
Morteza Safai
Boeing Research & Technology
Gary.e.georgeson@boeing.com

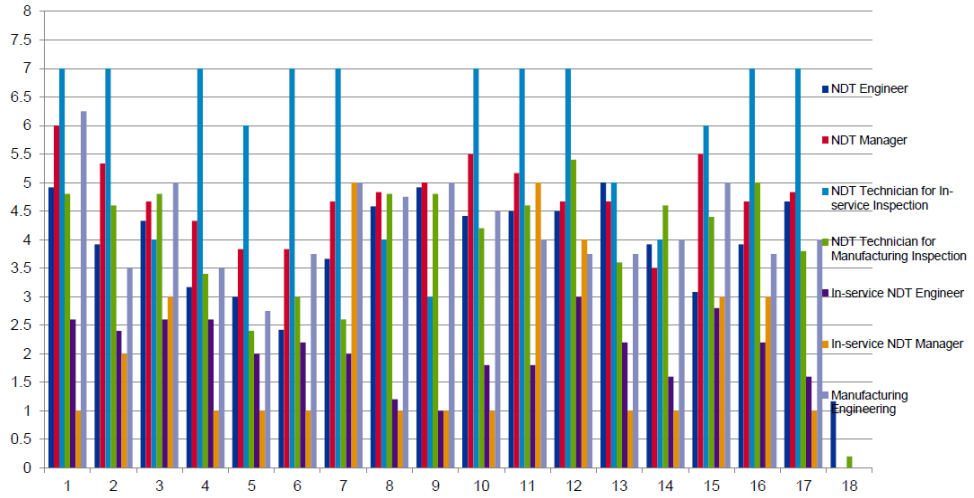
April 10-14, 2016
ASNT Spring Research Symposium
New Orleans, LA

NDE is hard!



There is room for improvement

Where is further development needed, according to those working fabrication issues?



We agree!

What does inspector deal with?

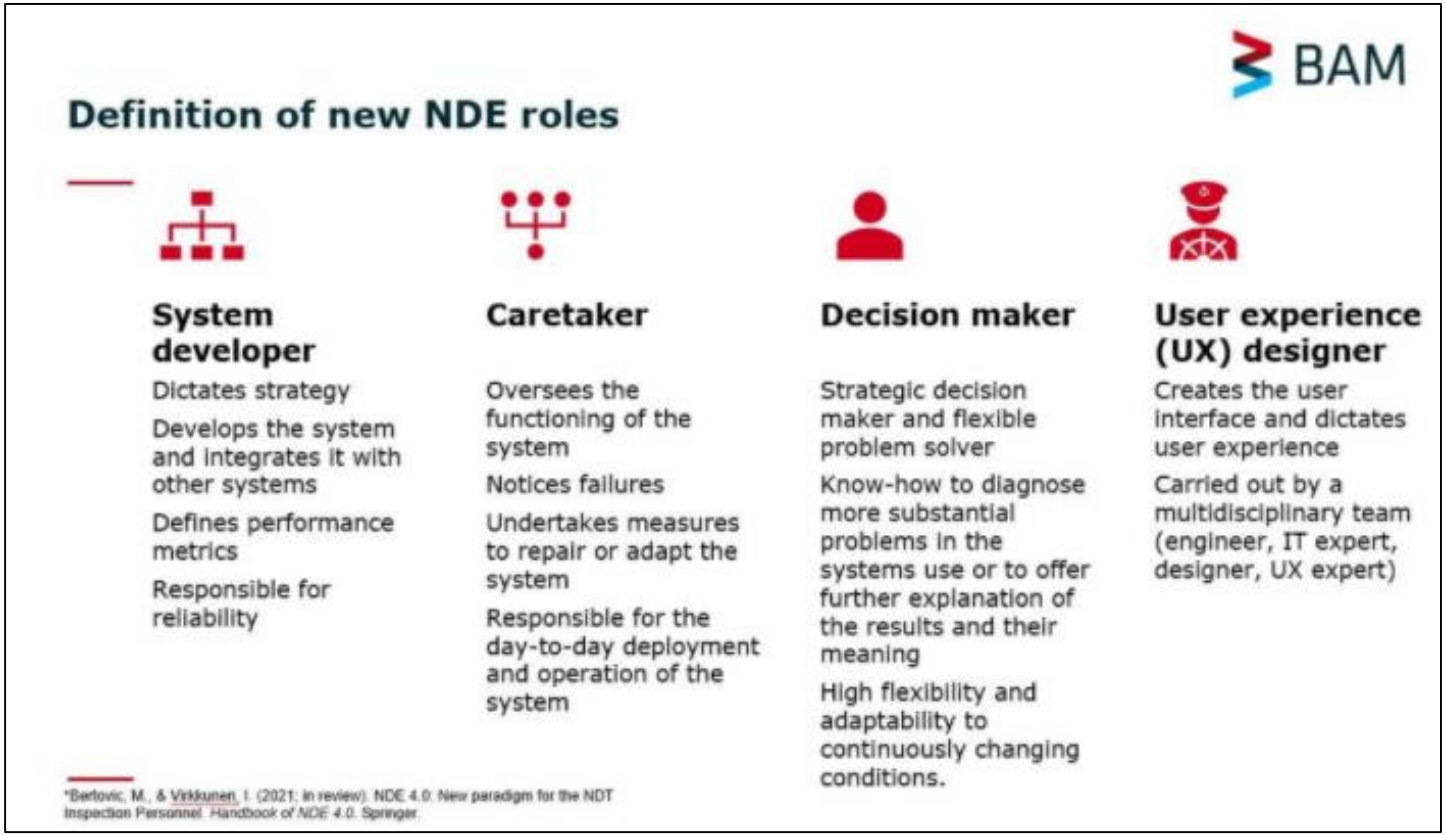
- Robotics, sensors, signal path, data acquisition, inspection techniques, standardization, CAD, M&P, probability of detection, defect characterization.

What are minimum education requirements for an ASNT Level 3?

Don’t expect your inspector to know it all!

- Minimum education is zero.
  - On the job training plus pass the exams.
- Inspectors rely on the vendors for equipment expertise.
- Inspectors rely on the M&P people for relevant M&P information and defect criteria.
- Do you have engineering support? Does your engineer have background in NDE?

What is the Level III role?



Other problems

- NDE data proprietary.
  - Vendors want all your business.
    - Pick best?
  - Supplier audits?
  - Data analytics?
- With ISU CNDE we have written a specification and provided code to support an open NDE data file format.

Other problems

- Composites manufacturing evolving.
  - OOA material systems have more porosity.
  - Built up structures: too expensive to scrap.
    - Need better NDE information to do better repair
  - Built up structures, curvatures, joints are harder to inspect.

How are we going to do this?

- Quick NDE refresher.
- NDE problems and possibilities.
- Digital transformation for NDE.

Digital transformation for NDE

- Initial development and validation via simulation
- Rapid prototyping
- UT full matrix capture and post processing
- Intelligence Augmentation during inspection
- Assisted Defect Analysis post inspection
- Digital handoff to engineering

Simulation tools for NDE

- Commercial software tools can be used to predict coverage for UT, RT, ET.
  - Am I getting sound everywhere, and I am getting sound BACK from defects?
  - High fidelity modeling of arbitrary defects in 3D in PMC's is not mature.

Simulation provides insight into complex signals – clues to detection

Probe: 5MHz, Incident Angle in H2O 45°

Observations: No defect

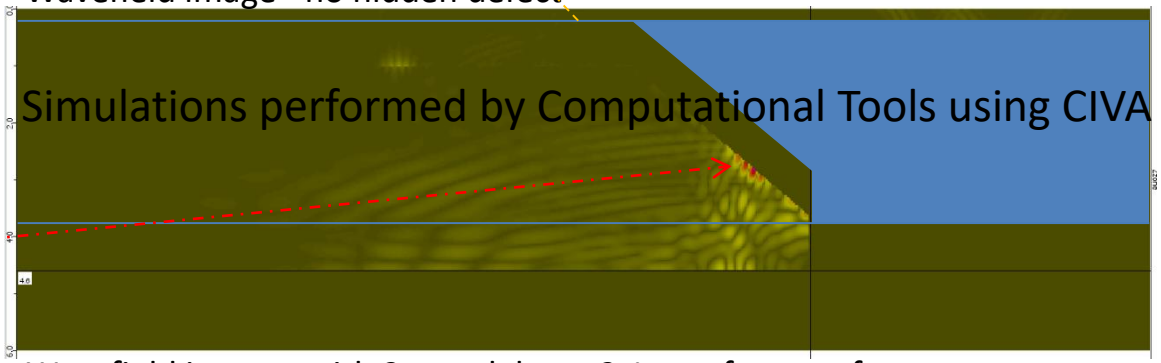
- qS mode wavespeed close to water (~1800 m/s compared to 1483 m/s)
- qS wave deflection not perpendicular to propagation path (anisotropy)
- Surface wave generated and scatters from countersink corner with hole
- Far corner reflection observed following countersink corner signal

Observations: Hidden delamination

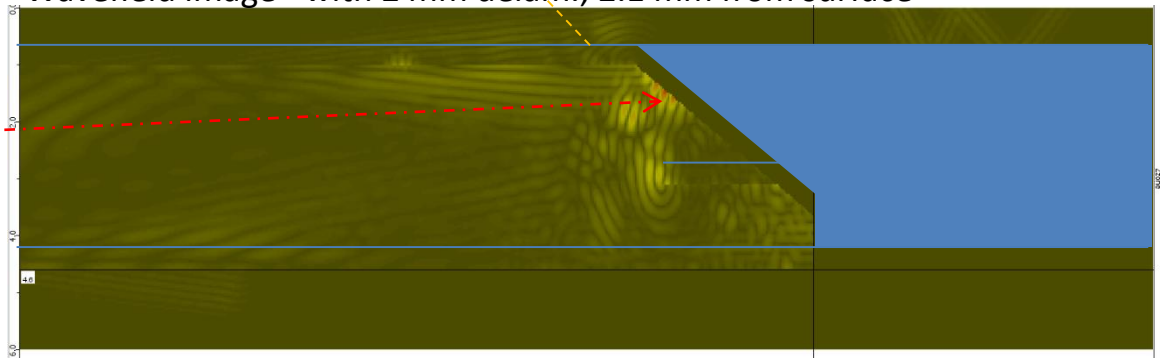
- Delam. produces early reflection (both specular and corner diffraction) before countersink corner(s)
- Delam. also blocks later hole corner reflection signals

Time: 16.88 μs

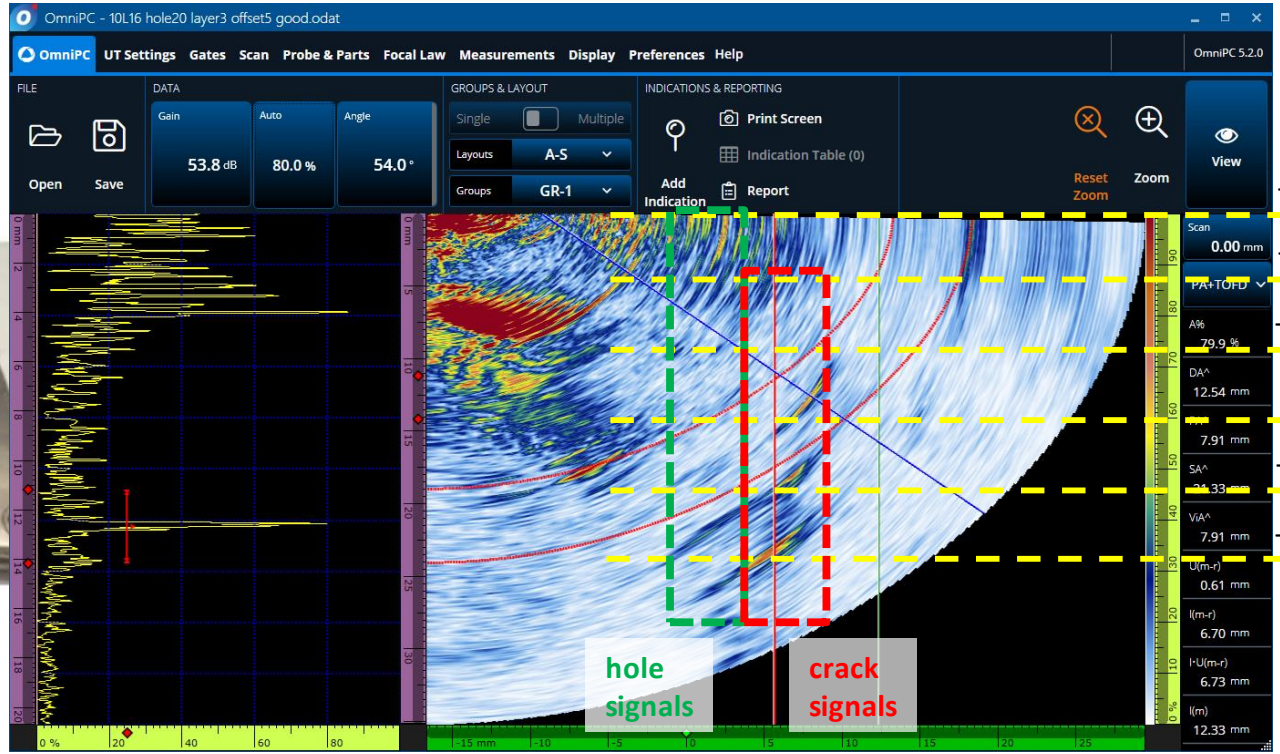
Wavefield image - no hidden defect



Wavefield image - with 2 mm delam., 2.1 mm from surface



Simulation informs complex inspection interpretation – enables ADA



Rapid prototyping for fast response

USSF

AFRL

Delivering Comprehensive Inspection Solutions for the C-130 Propeller

ASIP Conference 2021

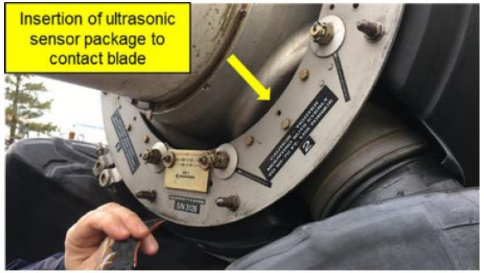
Ryan Mooers[1], John Brausch[1], Ken LaCivita[1],
Nicholas Bunnell[2], Mike Fisher[3]

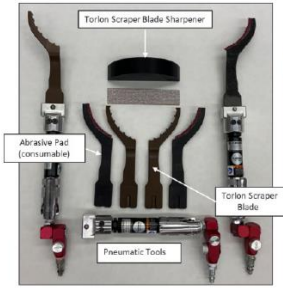
[1]Materials Integrity Branch, System Support Division
Materials and Manufacturing Directorate
[2]NDI Program Office, Warner Robins Air Logistics Complex
[3]C-130 Engineering, Warner Robins Air Logistics Complex

USSF AFRL

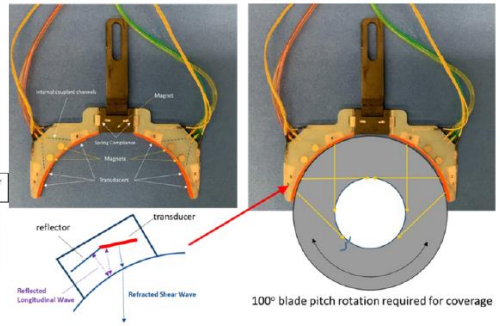
On-Wing Inspection Development

- ISO level inspection needed to detect cracks on-wing
- Limited access (spinner removal only), and blade rotation (≤ 100 degrees)
- Developed multi-element ultrasonic transducer
- Standalone self contained kit employs field available ultrasonic instrument
- Requires blade cleaning
  - 2 stage cleaning kit developed
- System features:
  - 6 elements, captured water column w/ flex. membrane
  - Novel reflector design monitors coupling
  - Couplant supplied through custom pressurized system
  - Sequencer allows for use on single channel instrument





Cleaning Tools



100° blade pitch rotation required for coverage

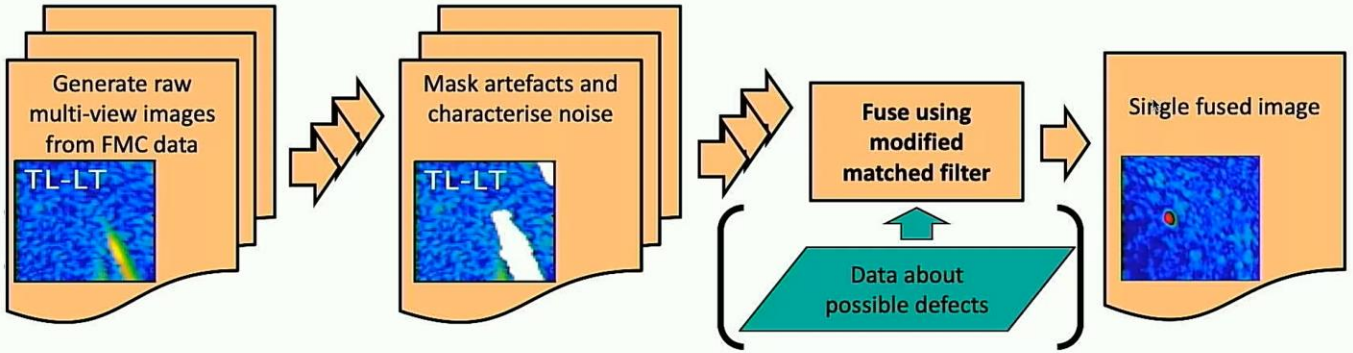
THE AIR FORCE RESEARCH LABORATORY

19

Full matrix capture for improved UT

Multi-view imaging

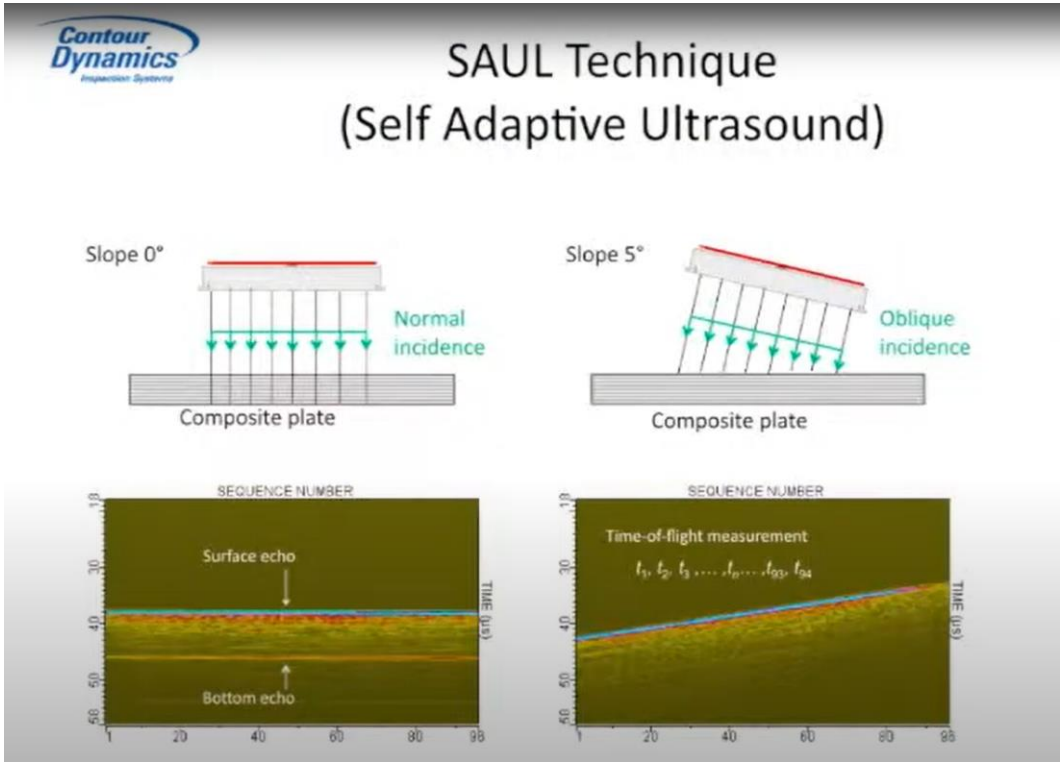
- Workflow – fuse images using statistical method to maximise sensitivity



bristol.ac.uk ndtatbristol.com

Paul D. Wilcox, "Computational ultrasound: how arrays and data are reshaping ultrasonic NDE ," Proc. SPIE PC12047, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XVI, (18 April 2022); https://doi.org/10.1117/12.2622246

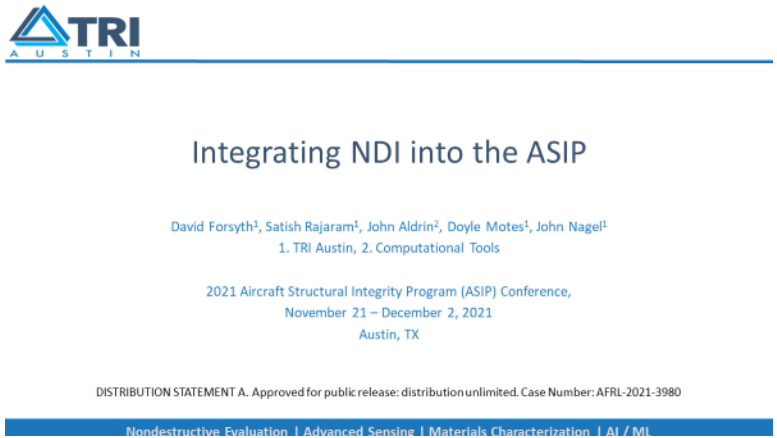
Better performance for complex geometries



https://www.tdnde.com/about-us/

Help inspector do the right job, right

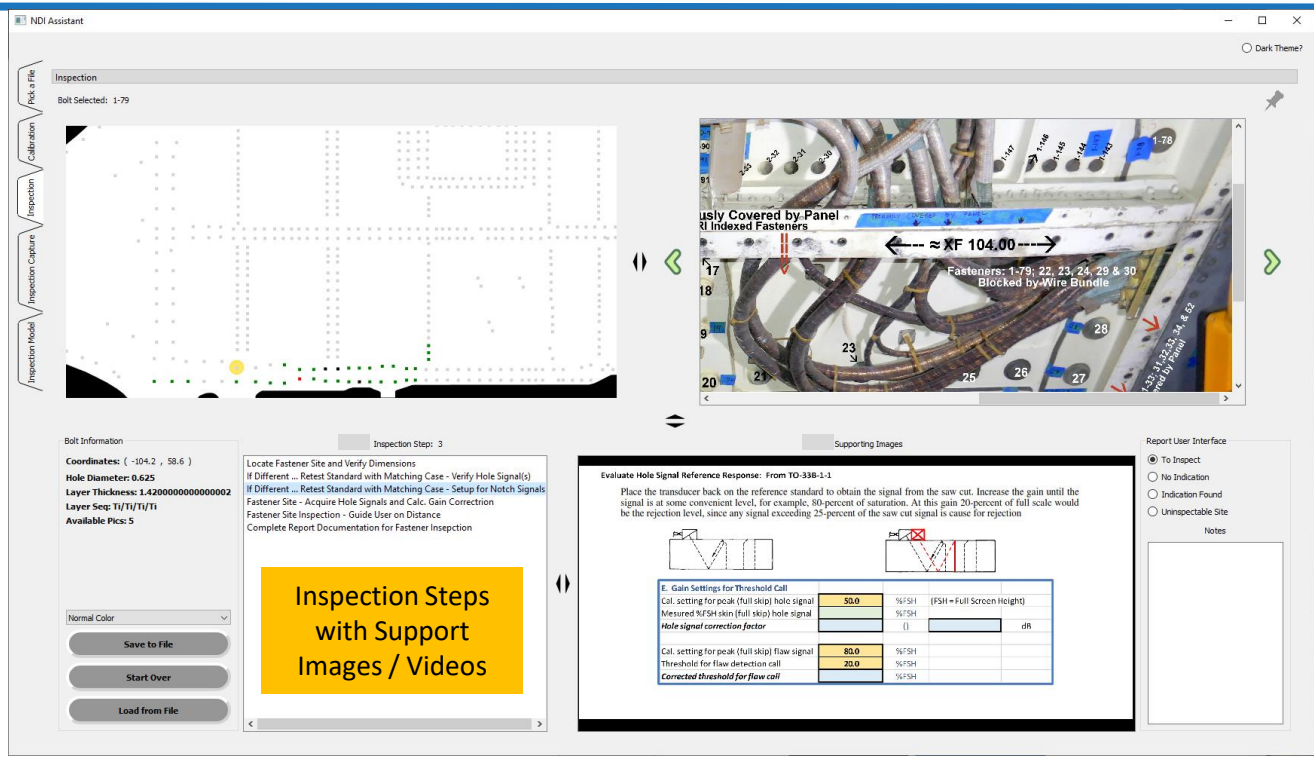
- "Intelligence Augmentation" is the term for a variety of possible technologies that can be used to help the inspector.
  - Correct instrument settings.
  - Correct calibration.
  - Go to the right location.
  - Data was collected and is good.



NDEAssistant Features - Inspection Support

Inspection Assist Tools

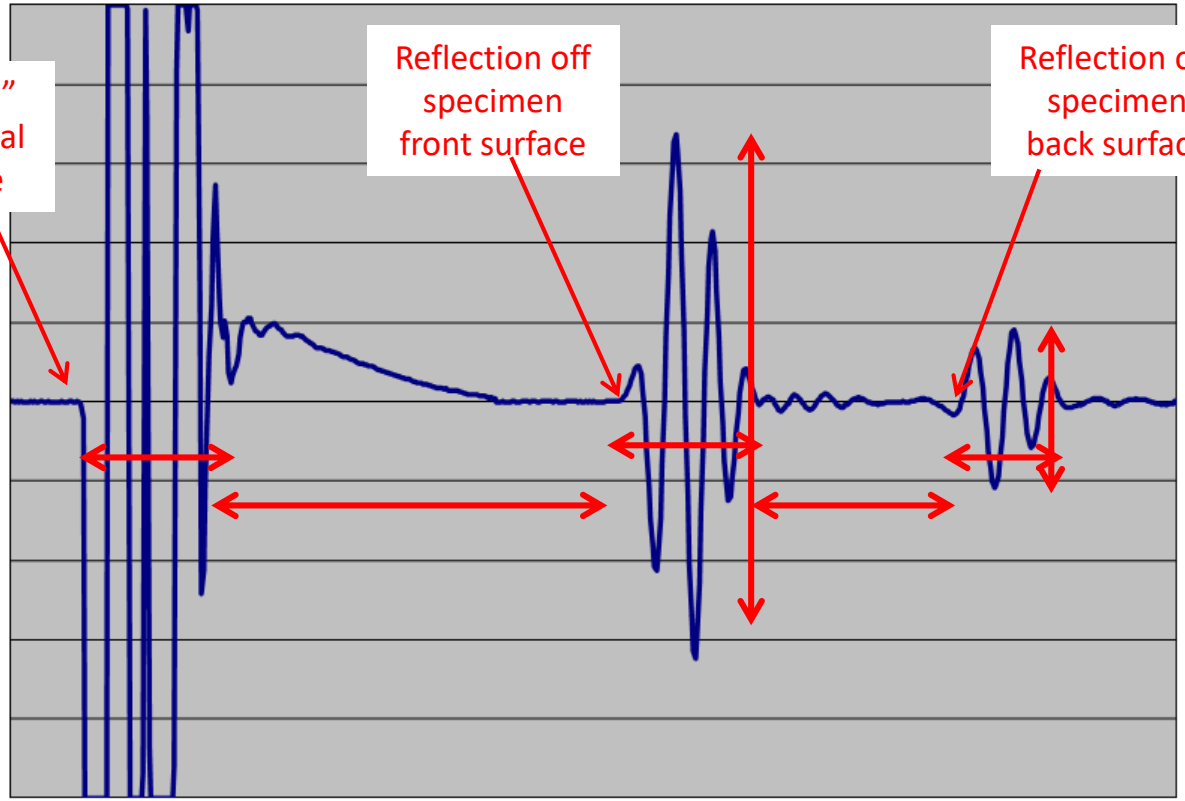
- **Input Data Structure(s):**
  - Inspection Panel View
- **GUI Interface:**
  - Interactive CAD View
  - Linked photos of inspection sites
  - **Presentation of Workflow**
    - Inspection Steps
    - Support Documentation
  - NDI Results - View
- **Output Data Structures:**
  (Inspection Results / Reporting)



Assisted Defect Analysis

- ADA, ADR, …
- TRI Austin and Computational Tools philosophy is to use ADA to find indications
  - Pixels that violate criteria
- Then inspector dispositions indications.
  - Relevant
  - Non relevant

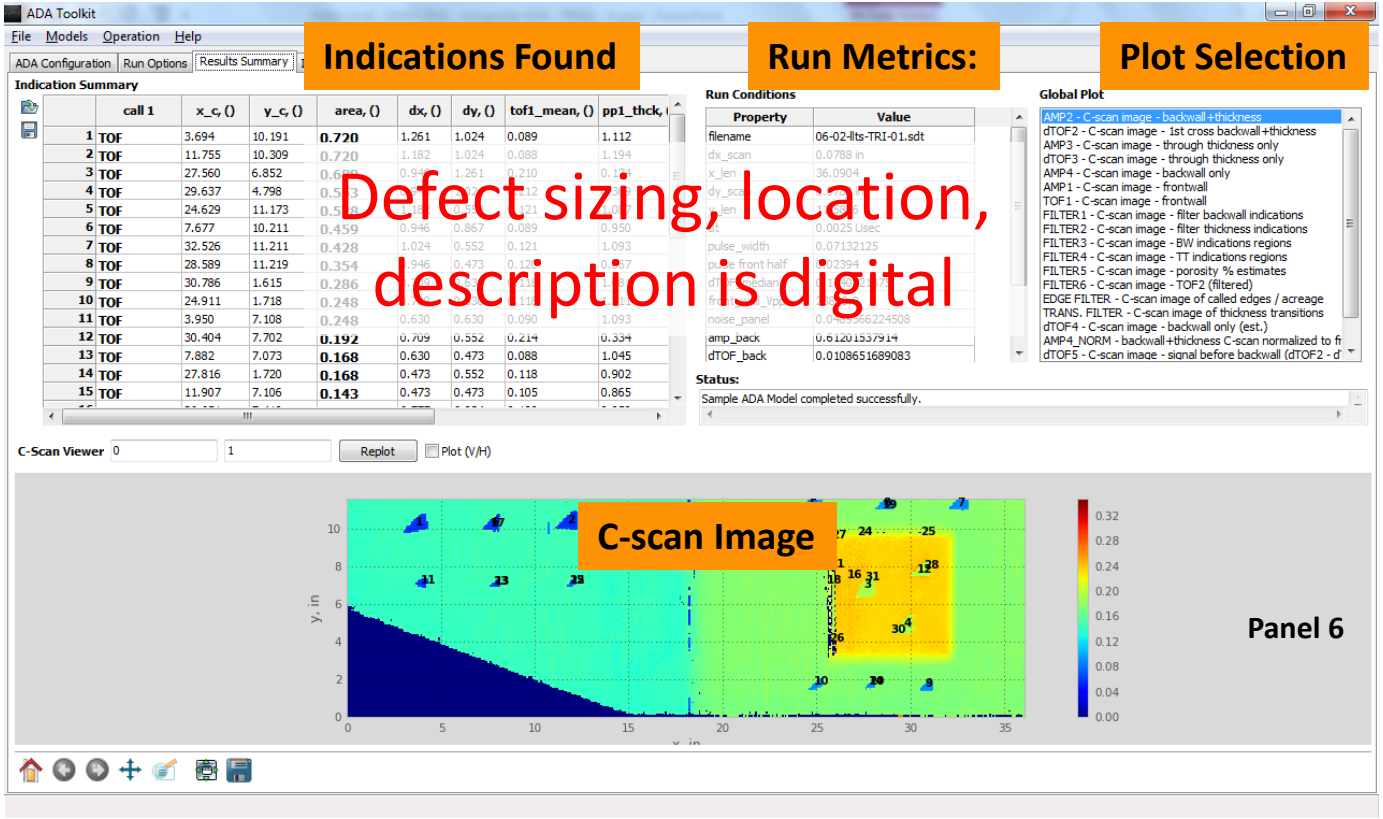
Automated Defect Analysis



How are ultrasonic inspections interpreted?

- Criteria of signal amplitude and signal time of flight.
- Criteria of area.
- Criteria of nearest neighbors.
- NO DEFECT TYPING.

ADA Results Summary

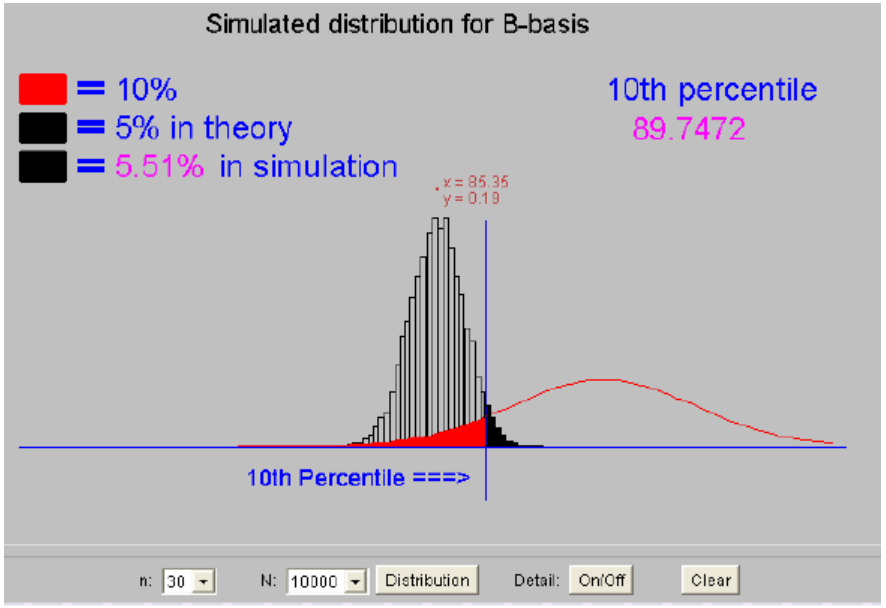


After NDE – digital transfer of results

- Two options:
  1. Part is good, process continues.
  2. Part is bad. Go to Manufacturing Review Board (MRB).

Option 1. Passed. Is that all you want to know?

- Part has passed NDE.
- What do you know about the part?
- Tracking quality metrics from NDE?



The internet browser-based simulation program is available at NCAMP website http://www.niar.wichita.edu/coe/ncamp_media.asp

Option 2. Did not pass. What to do and why?

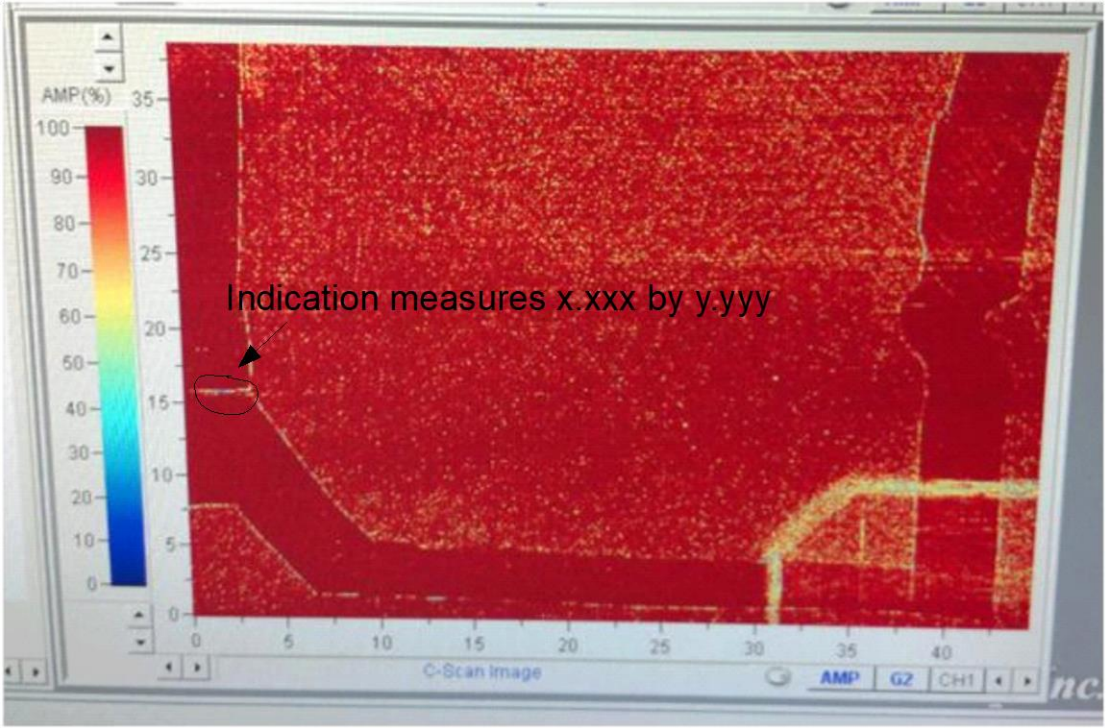
- There is an indication in the NDE data that violates your defect criteria.
- If the part is low cost, discard.
- If the part is high cost, go to Manufacturing Review Board.

- How does NDE support the MRB?

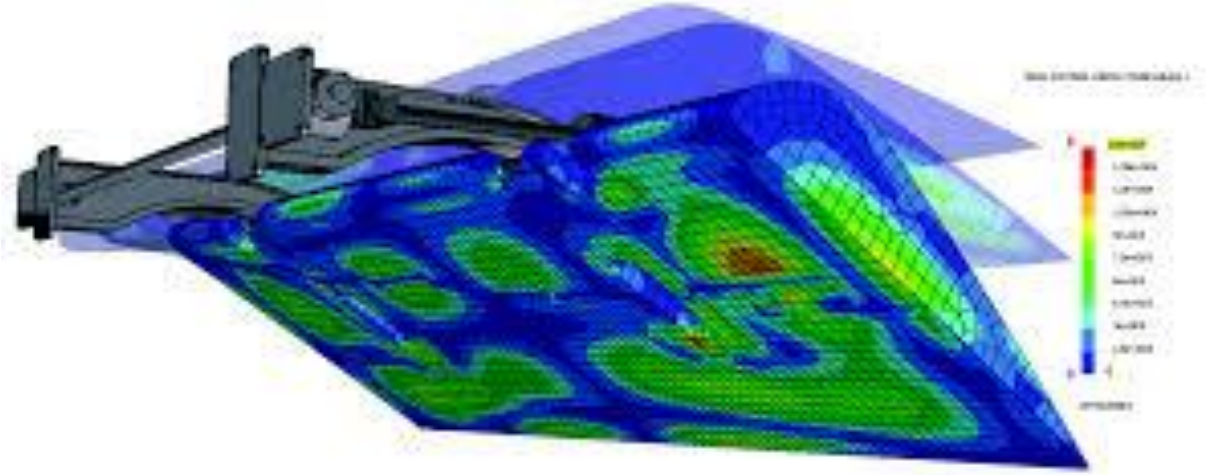
Old school NDE and MRB

- Results of NDE are translated by hand into finite element model.
  - Reliable? Reproducible?
- Unknown properties of defect.
  - “Open hole” criteria used in design.
- “Effects of defects” models require detailed definition of defect.

Digital thread broken?



Where, how to modify model?

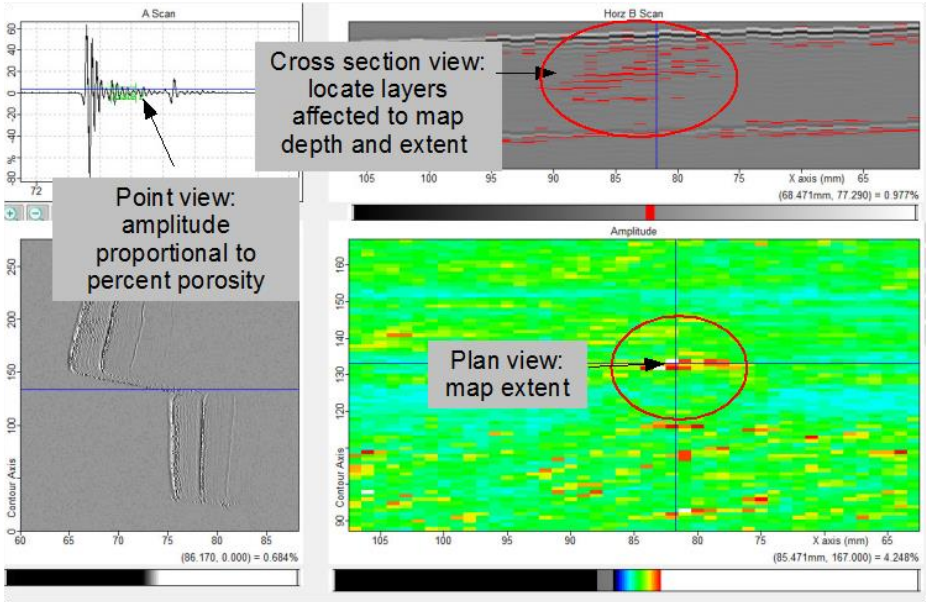


Technical opportunities in Composites

- Detection, typing, and spatial registration of discontinuities in 3D.
  - FOD/delam/disbond, porosity
  - Wrinkles
  - Matrix rich
- Bulk materials properties.
- Ply count and fiber direction through the thickness.
- Weak bond detection.

From Indication to Properties

- Ultrasonic inspection data can be used to describe defect type and dimensions.



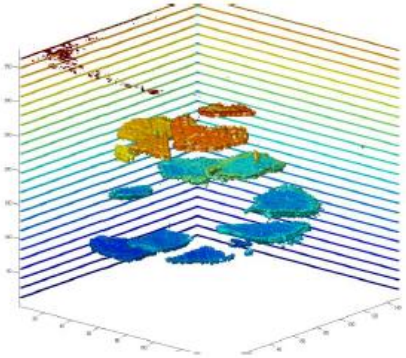
Quantitative Defect Characterization

Experimental Results

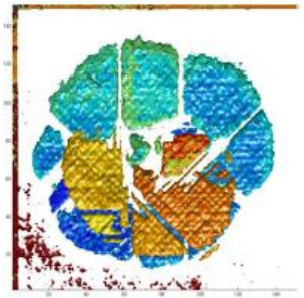
Nondestructive Evaluation Sciences Branch

- Multi-frequency wavenumber analysis

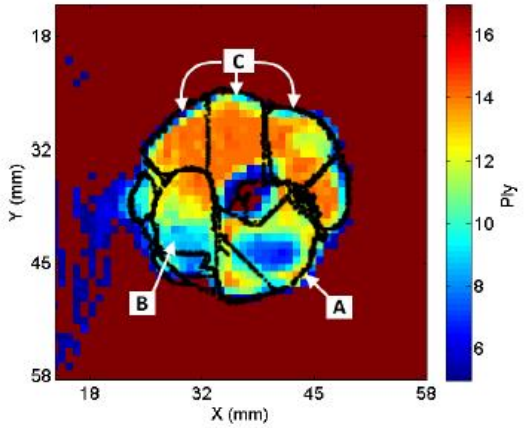
Immersion Ultrasound



Immersion Ultrasound



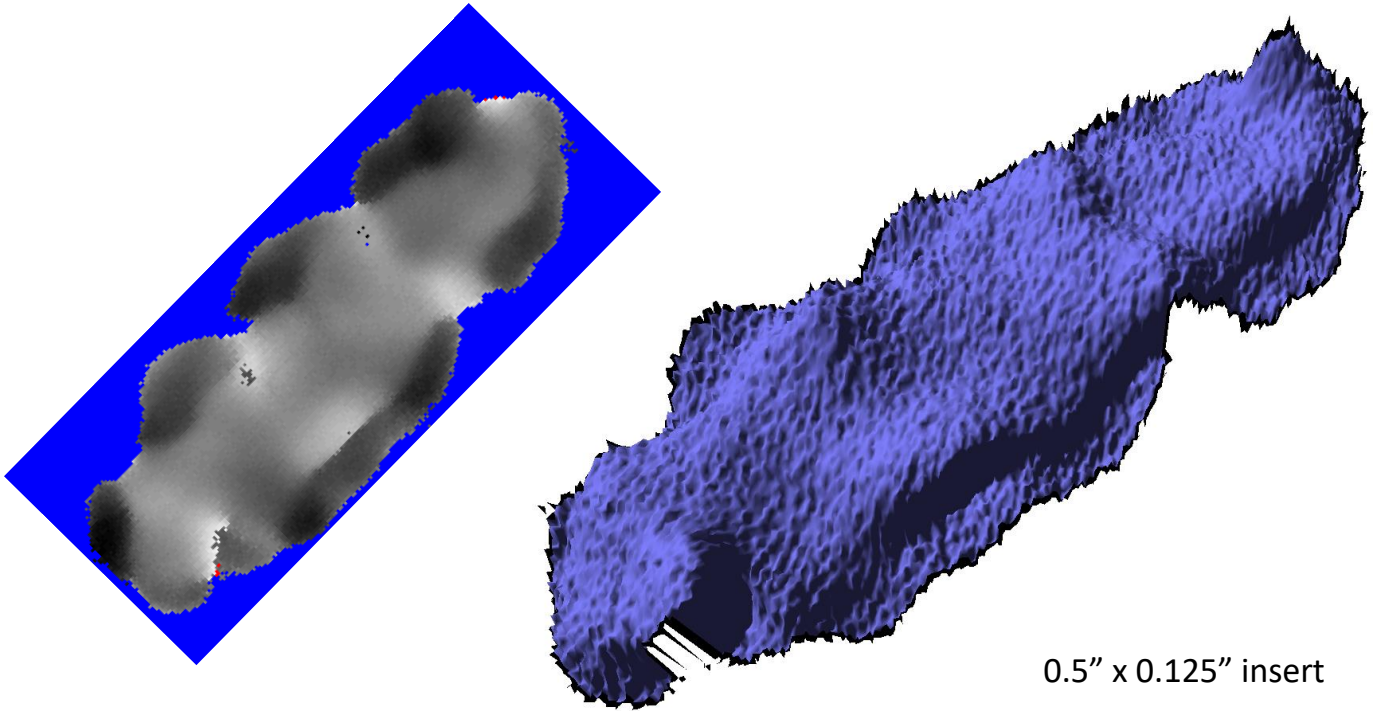
Noncontact LDV Wavenumber Analysis



[1] Juarez, P. and Leckey, C. "Multi-frequency Local Wavenumber Analysis and Ply Correlation of Delamination Damage". *Submitted to Ultrasonics*

Defect characterization

Defects can be mapped in 3 dimensions.

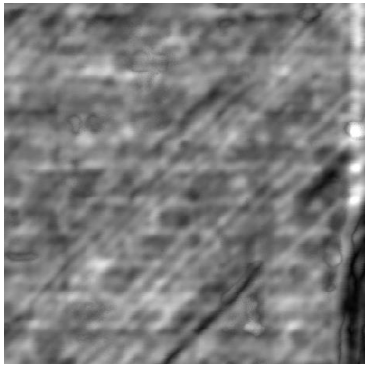


0.5” x 0.125” insert

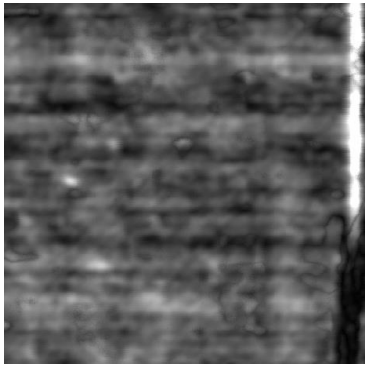
Determining fiber direction

Max signal per ply.

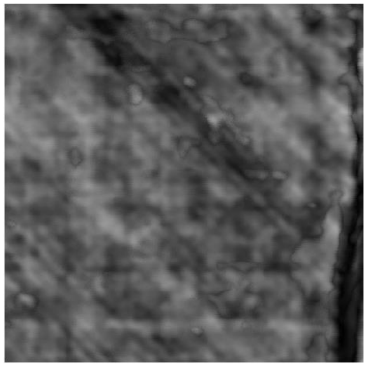
45°



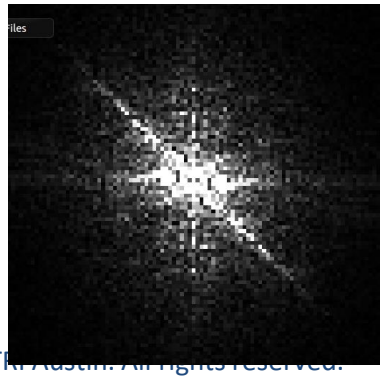
0°

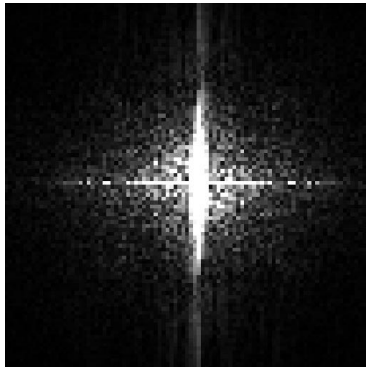


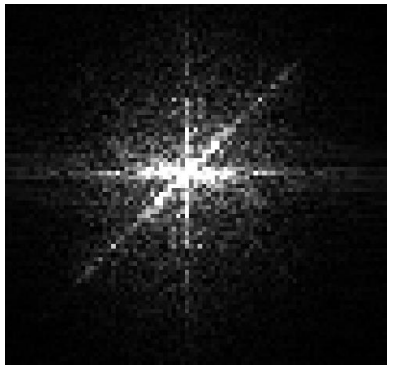
-45°



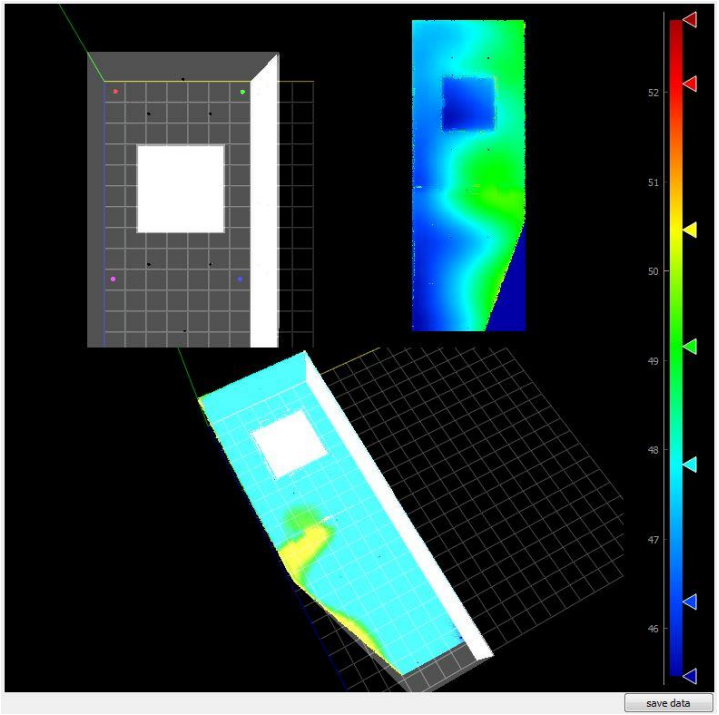
2D FFT





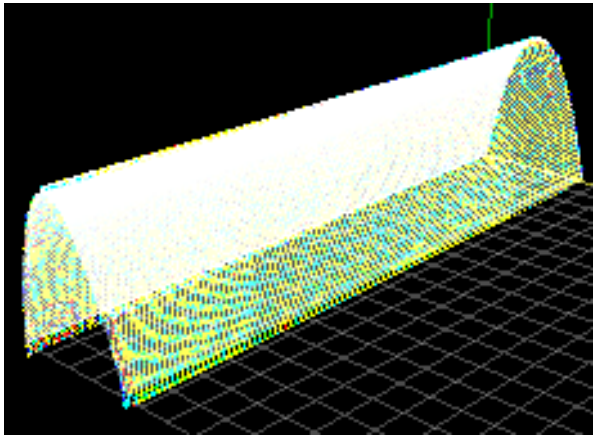


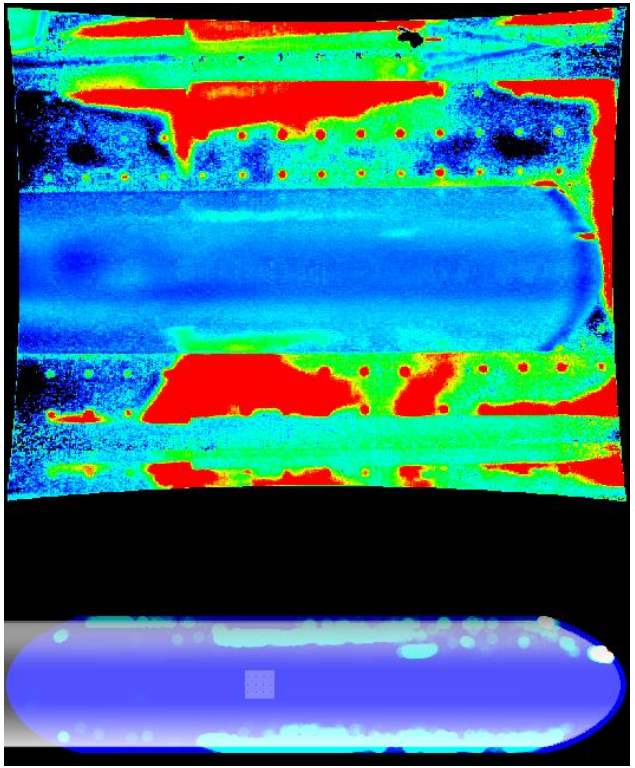
Incorporating into Digital Twin



- NDE data is mapped to CAD coordinates
- Ensures full inspection coverage
- Highlight difference between as-designed and as-built
- Ties data to digital thread

Combine data in CAD space





Conclusions

Old school

NDI Shop

- Find it on “C scan”.
- Go handscrub it.
- [all mgmt shows up and argues about what it really is]
- Back to computer, use software to draw around it and make dimensions. Export to image file.
- Email to engineering.
- On to next part.

Engineering

- Locate on part.
- Check allowables.
- Check knockdowns.
- Run local model.
  - where is it in plane?
  - where is it in thickness?
  - what mechanical properties?
- Release, repair, scrap.

State of the art

NDI Shop

- Algorithm finds it on “C scan”.
- Level III review.
- Go handscrub it.
- Back to computer, use software to draw around it and make dimensions. Export to image file.
- Email to engineering.
- On to next part.

Engineering

- Locate on part.
- Check allowables.
- Check knockdowns.
- Run SI model.
  - √ where is it in plane
  - √ where is it in thickness
  - √ what mechanical properties
- Release, repair, scrap.

Digital transformation for NDE

- Initial development and validation via simulation
- Rapid prototyping
- UT full matrix capture and post processing
- Intelligence Augmentation during inspection
- Assisted Defect Analysis post inspection
- Digital handoff to engineering

Thank you!

- SME organizers.
- TRI Austin.
- Multiple Air Force and NASA sponsored programs have supported this technology.
  - No project data used in this presentation without prior clearance as noted on the charts.
- I appreciate your time and feedback.

David Forsyth
dforsyth@tri-austin.com
512-615-4451