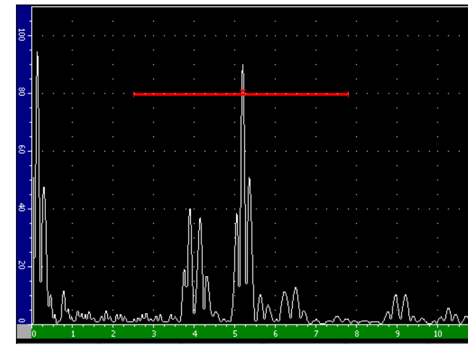
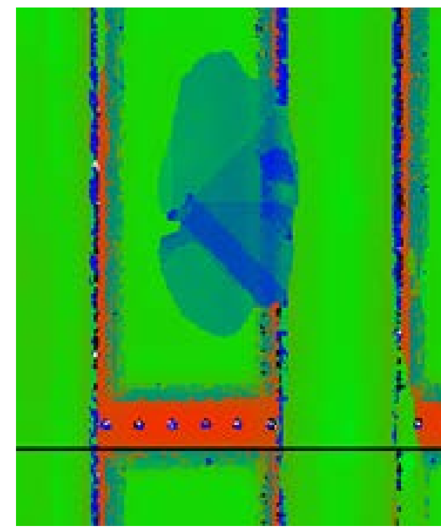
Inspection Methods for Characterizing Subsurface Impact Damage in Solid Laminate Aerospace Composites





Stephen Neidigk, Dennis Roach, Tom Rice, Randy Duvall
FAA Airworthiness Assurance Center
Sandia National Labs

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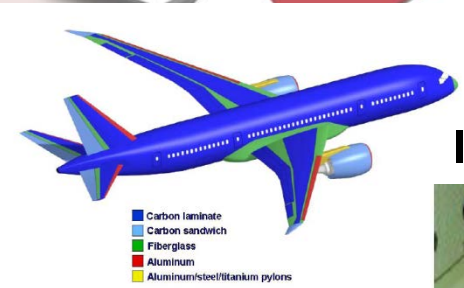
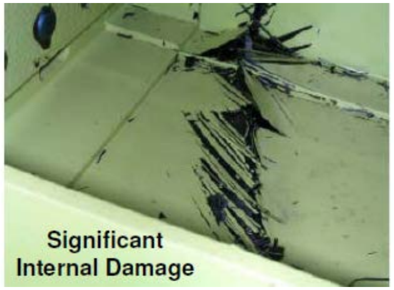
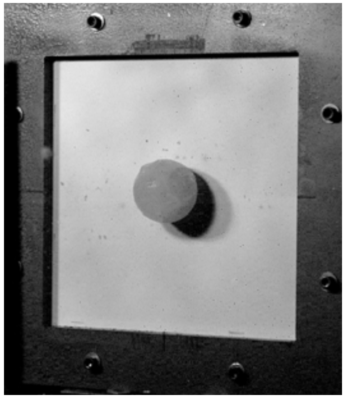
Presentation Outline



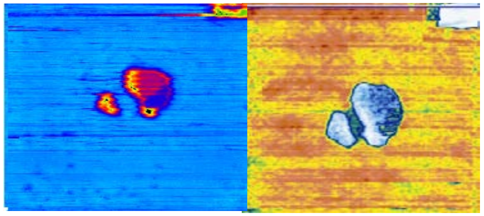
Introduction and Background



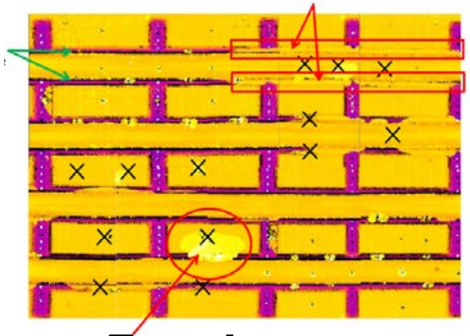
Motivation



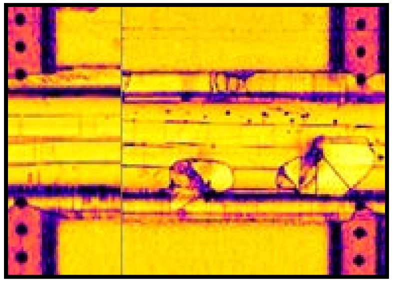
Ice Impact Damage on Laminate Plates



Side-by-Side Inspection Comparison of NDI Techniques



Conclusions



Full-Scale Panel Impact Testing

- Simulated Hail
- Blunt
- Hardened

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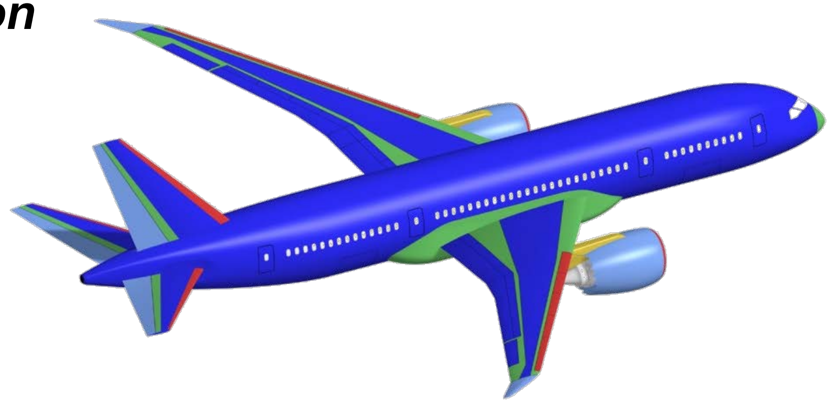
Program Motivation - Extensive/increasing use of composites on commercial aircraft and increasing use of NDI to inspect them

Composite Structures on Boeing 787 Aircraft

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



Composite Center Wing Box

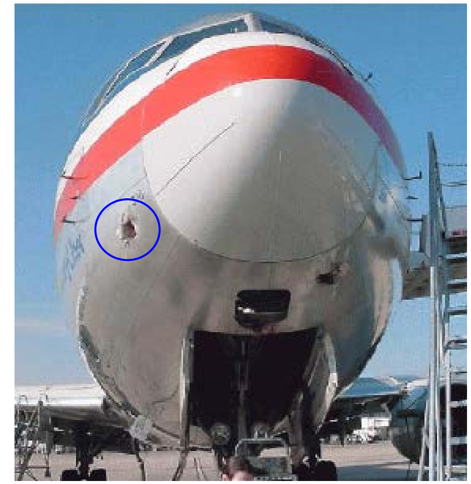
A380 Pressure Bulkhead

Program Goals: Assess & Improve Flaw Detection Performance in Composite Aircraft Structure

Sources of Damage in Composite Structure

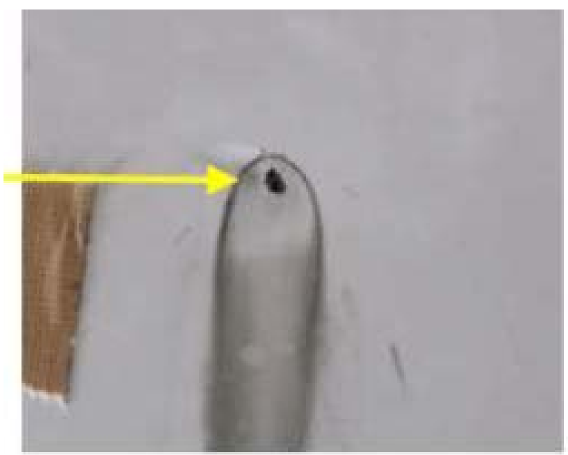
Lightning Strike on Thrust Reverser

Ground Support Equipment Impact



Bird Strike

Lightning Strike on Fuselage

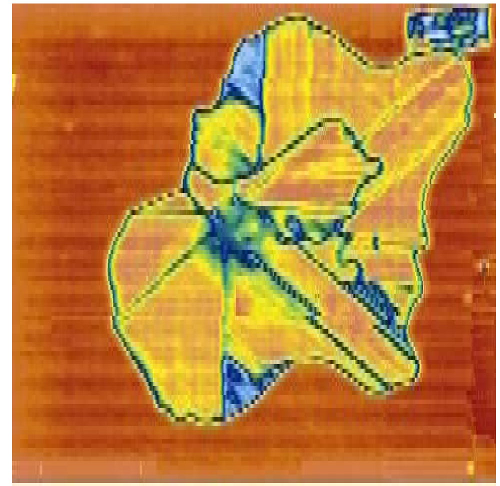


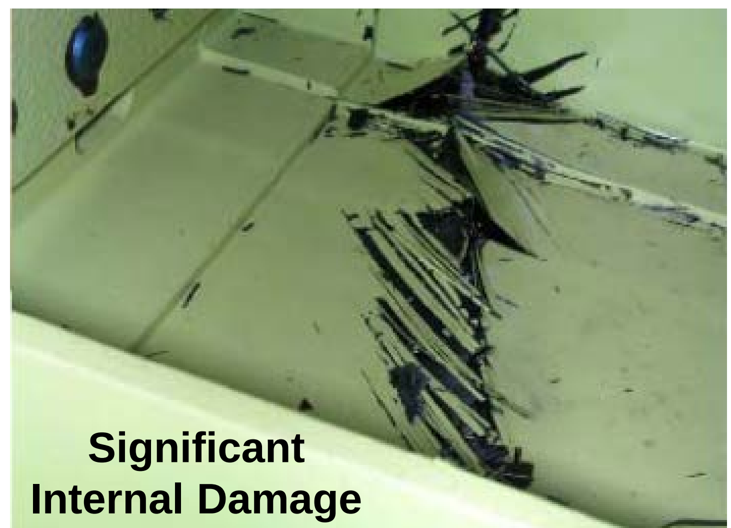
Towing Damage

Inspection Challenge – Hidden Impact Damage

Internal delamination from ice impact

Extent of visible damage | 44 in^2 Delamination





Source: Carlos Bloom (Lufthansa) & S. Waite (EASA)

AANC Composite Programs

- Industry wide NDI Reference Standards
- NDI Assessment: Honeycomb Structures
- NDI Assessment: Solid Laminate Structures
- Composite Heat, UV, and Fluid Ingress Damage
- Composite Repairs and Porosity
- Composite NDI Training and NDI Proficiency Specimens

COMMERCIAL AIRCRAFT COMPOSITE REPAIR COMMITTEE

Inspection Task Group

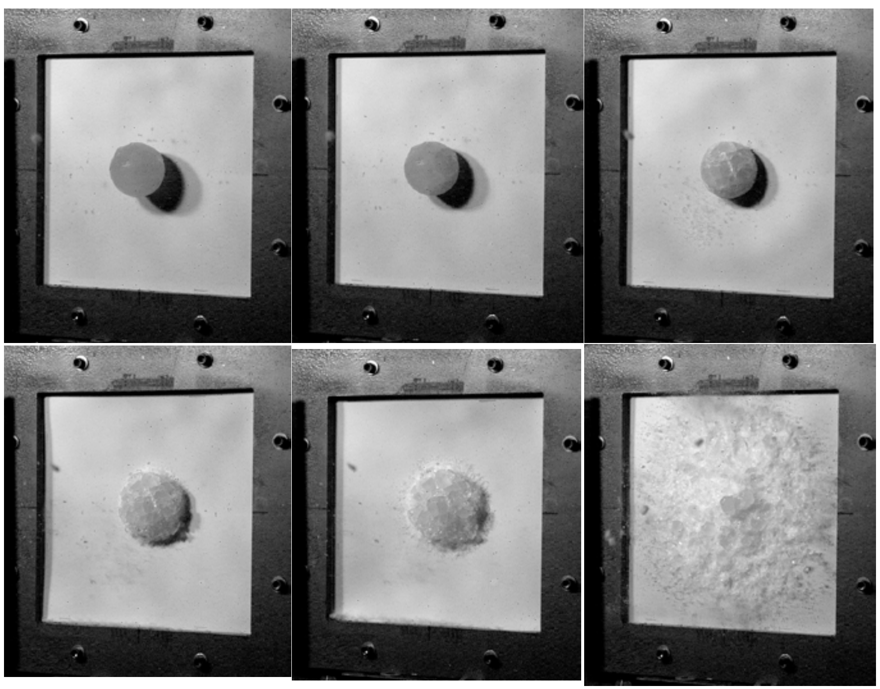
Composite Impact Study

Multiple impact parameters must be studied – hardness of impactor, low mass-high velocity impact, high mass-low velocity impact, angle of impact, surface demarcations & visual clues, panel stiffness

- Identify which impact scenarios are of major concern to aircraft maintenance
- Identify key parameters governing impact damage formation
- Relate damage threat & structural integrity to capabilities of NDI to detect hidden impact damage in laminates
- Develop methodology for impact threat characterization

Ice Impact Testing at UCSD

UCSD High Velocity Gas Gun

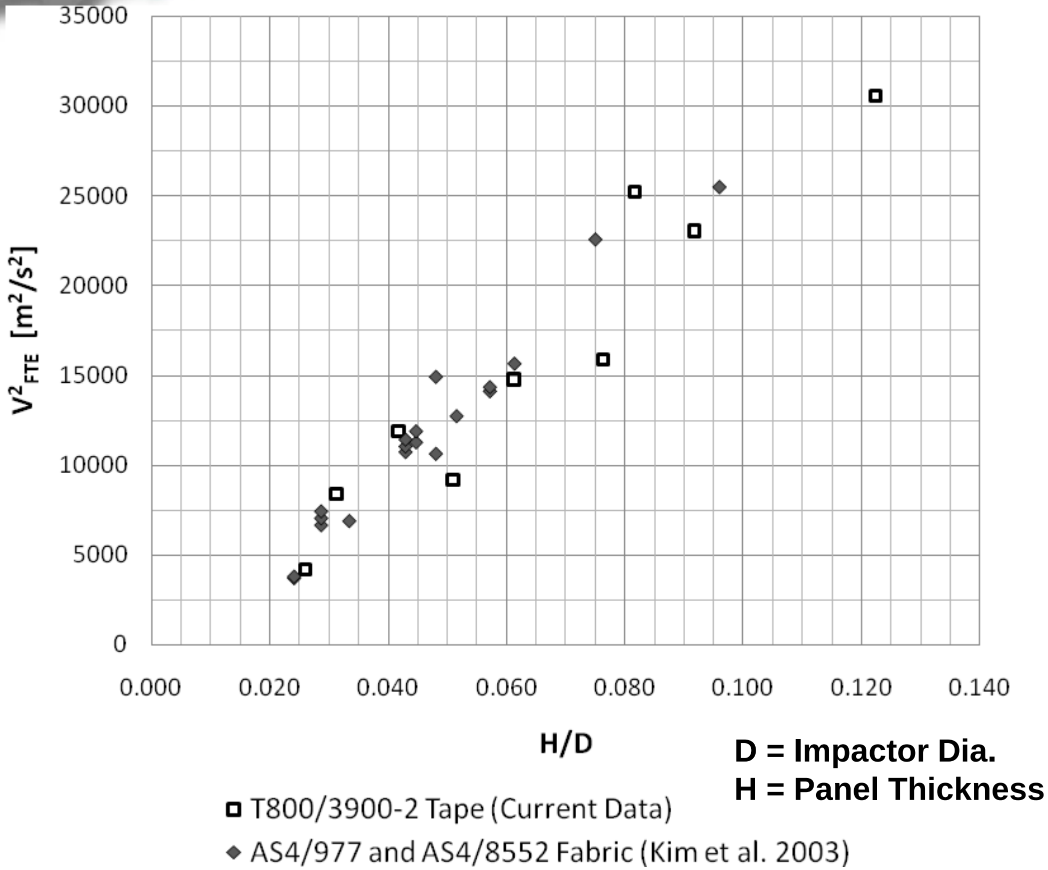


Still Images from 61 mm Ice Impact on 8 Ply Carbon Panel at 72 m/s

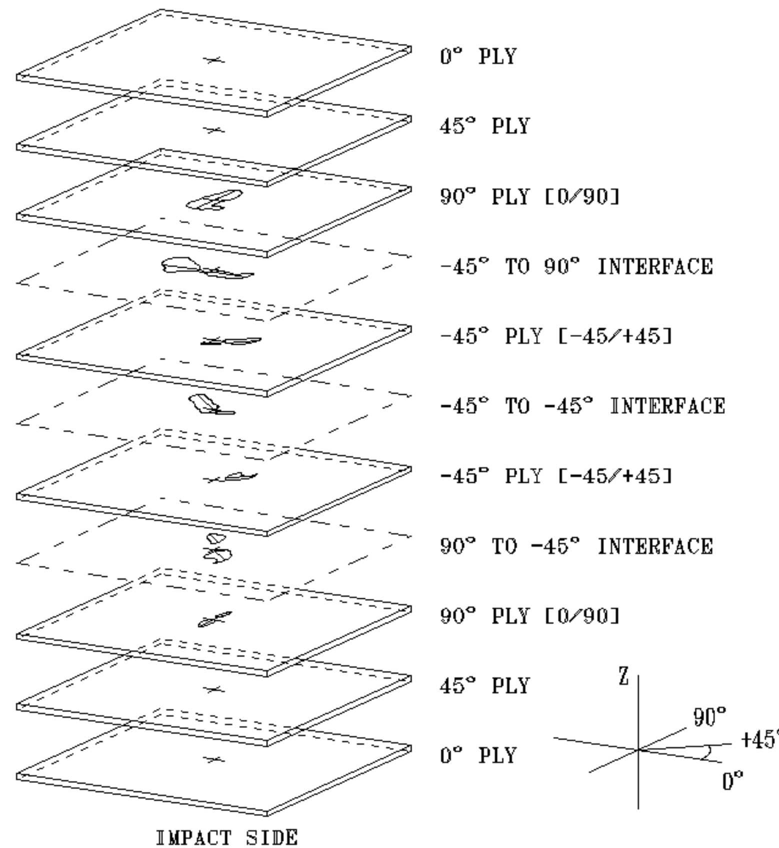
Joint Effort: UCSD (Prof. Hyonny Kim)

Sandia National Laboratories

Damage in Composite Laminates from Ice Impact



Failure Threshold (Energy) Velocity

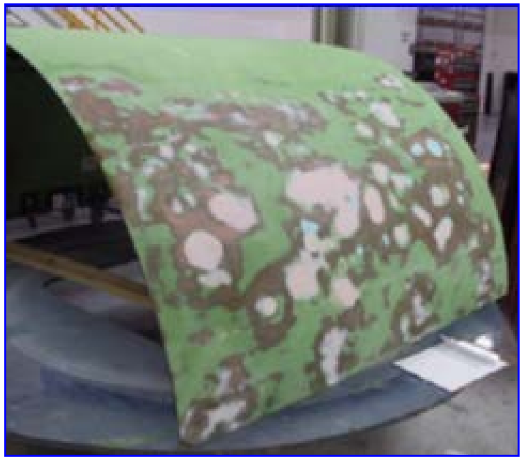


Impact-Induced Damage Morphology for 8 Ply Panel; 42.7 mm Ice at 120.4 m/s (267 J)

Selected panels were sectioned and observed by microscopy to map out the damage. The laminates develop the series of classic peanut shaped delaminations/fractures that stack together to give the overall appearance shown in the scans

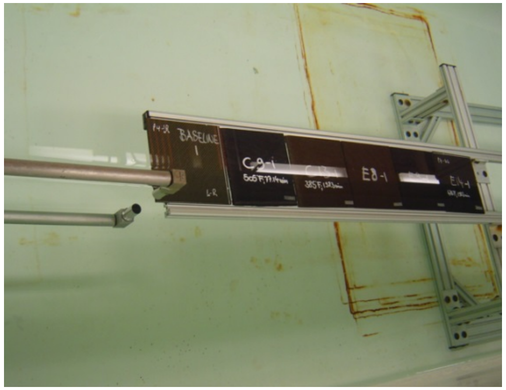
Composite Impact Study – Hail Impact Task Description

- 112 carbon composite panels were fabricated using BMS8-276N uniaxial material; consisted of 8, 16, and 24 ply configurations (12” x 12”)
- All panels were impacted with ice balls of different diameters and velocities to simulate hail and create various levels of impact damage
- The goal was to create damage associated with Failure Threshold ~ BVID range & complete NDI to evaluate the sensitivity of each method in detecting and sizing the damaged area (reliable, sensitive, gate deployment, cost effective)
- NDI methods used for this evaluation include: Through Transmission Ultrasonics (TTU), Phased Array UT, Pulse-Echo UT, Resonance, Flash Thermography, Damage Checker (PE-UT), Mechanical Impedance Analysis, Low Frequency Bond Test



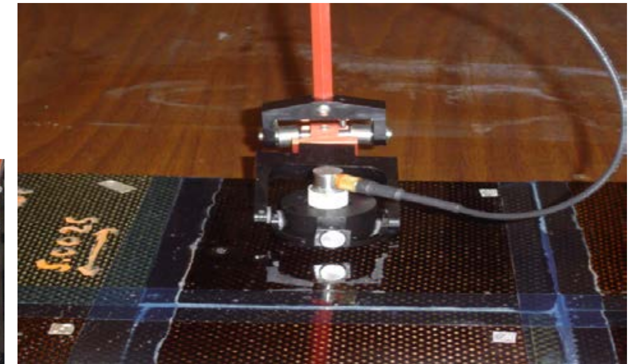
Joint Effort: UCSD (Prof. Hyonny Kim)

Composite Impact Damage – Inspection Methods Deployed

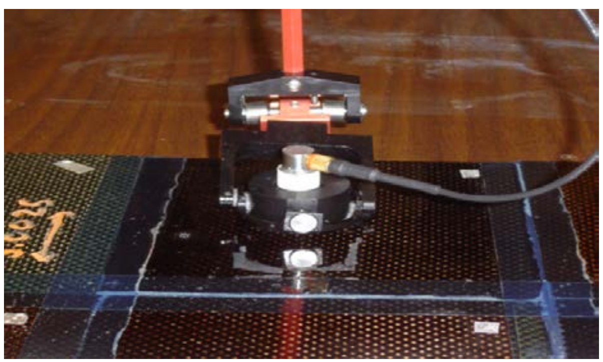


TTU

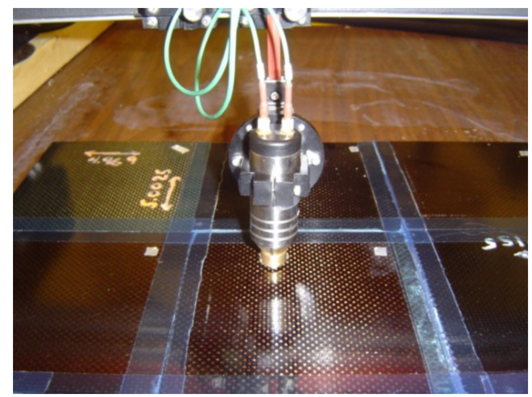
Thermography



MAUS PE



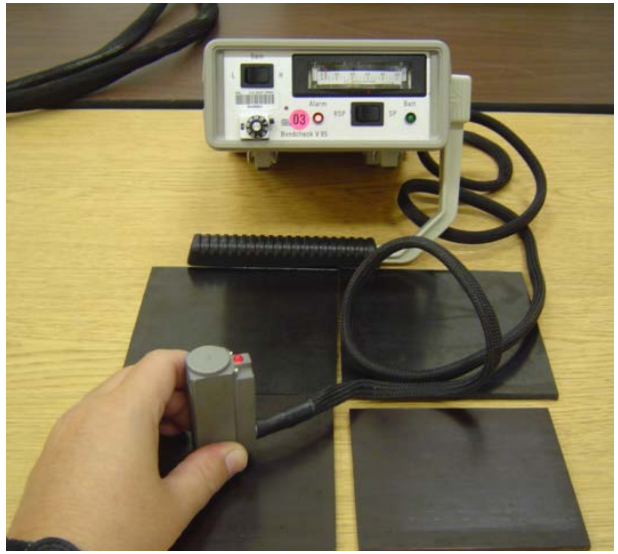
MAUS Resonance



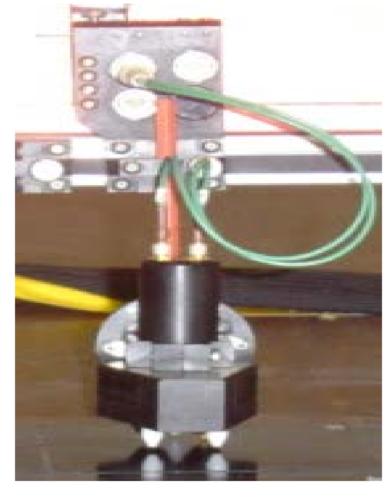
MAUS MIA

Composite Impact Damage – Inspection Methods Deployed

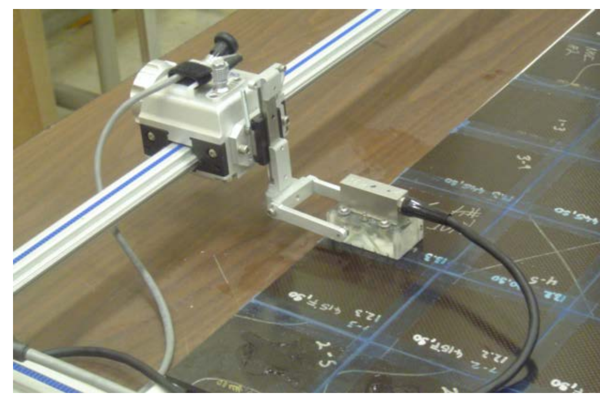
Damage Check Device (Pulse-Echo UT)



V-95 (Mechanical Impedance Analysis)



MAUS LFBT



Omniscan Phased Array UT

TC-16-25

Impact Energy (J) - 525.1

Example Result

Flaw Size MAUS PE (mm²) - 37,128

Flaw Size Omniscan PE (mm²) - 28,380

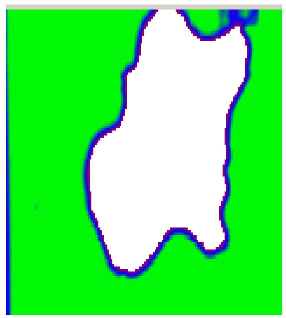
Flaw Size TTU UCSD (mm²) - 26439

Impact Velocity (m/s) - 212.44

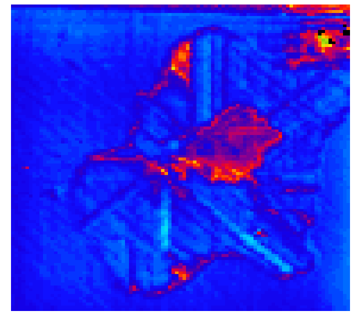
Projectile Size (mm) - 38.1

Picture

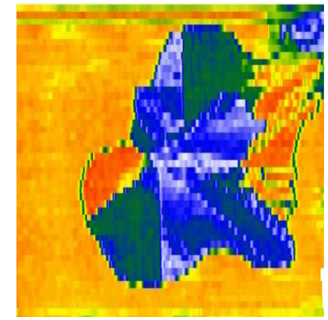
TTU



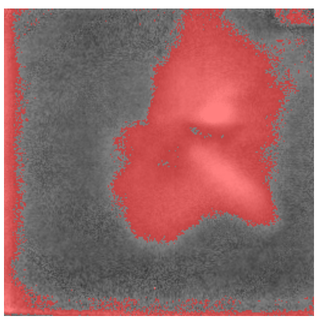
MAUS PE



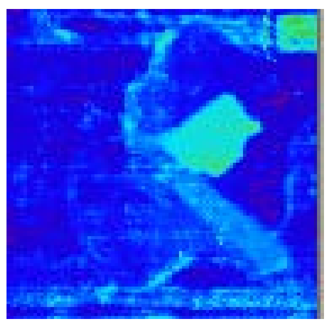
Omni PE



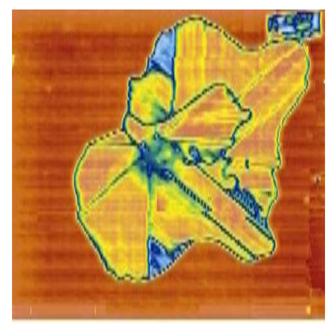
IR



MAUS Resonance



Omni PA

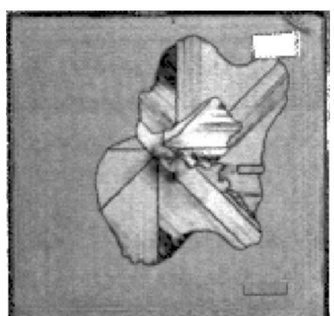


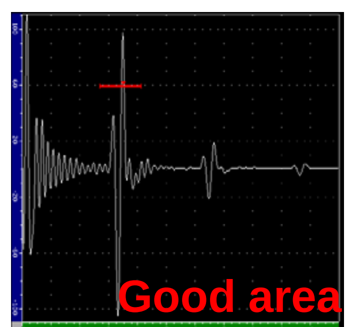
Ramp Damage Checker

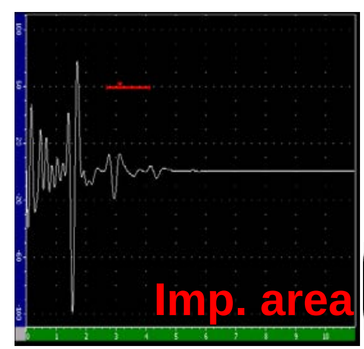
(flaw indicated)

Y

Laser UT







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TC-24-19

Impact Energy (J) - 1,268.1

Example Result

Flaw Size MAUS PE (mm²) - 9,413

Flaw Size Omniscan PE (mm²) - 9,439

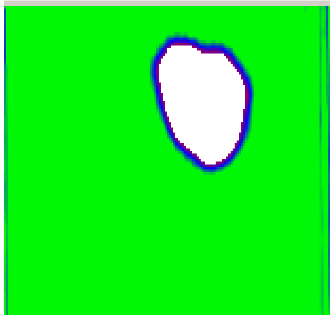
Flaw Size TTU UCSD (mm²) - 8,022

Impact Velocity (m/s) - 153.46

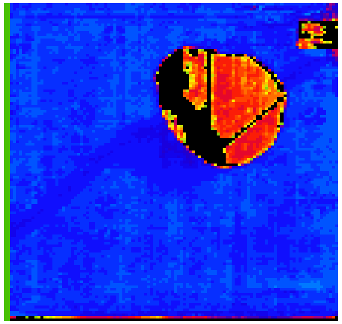
Projectile Size (mm) - 61

Picture

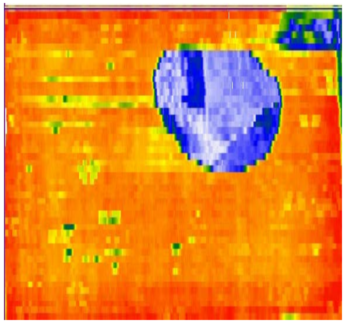
TTU



MAUS PE



Omni PE



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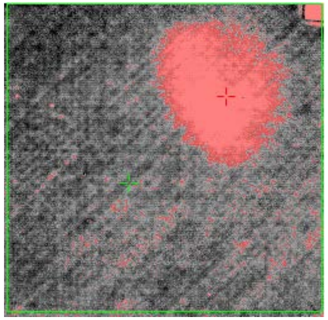
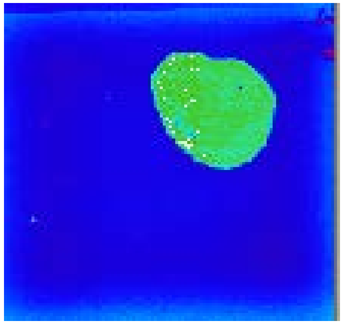
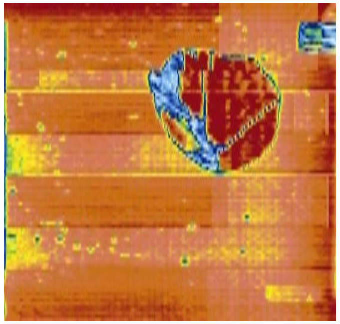


MAUS Resonance

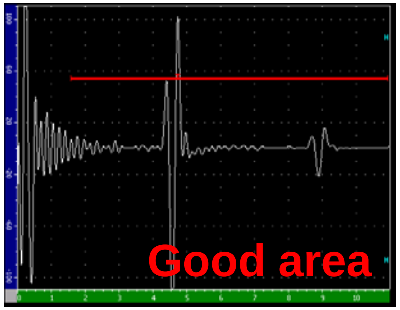


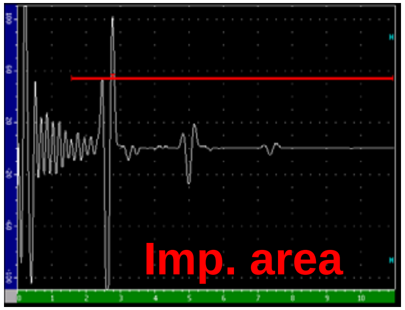
Omni PA



Ramp Damage Checker
(flaw indicated)

Y





TC-08-29

Impact Energy (J) - 306.7

Example Result

Flaw Size MAUS PE (mm²) - 703

Flaw Size Omniscan PE (mm²) - 554

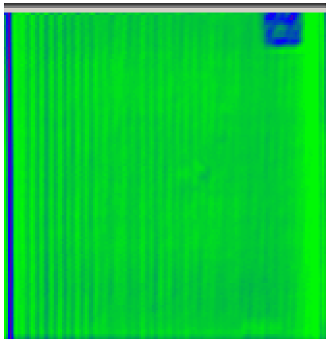
Flaw Size TTU UCSD (mm²) - 0

Impact Velocity (m/s) - 99

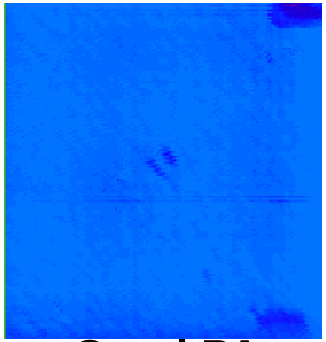
Projectile Size (mm) - 50.8

Picture

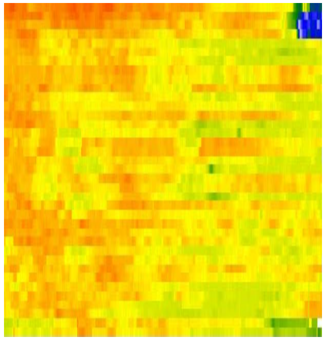
TTU



MAUS PE



Omni PE



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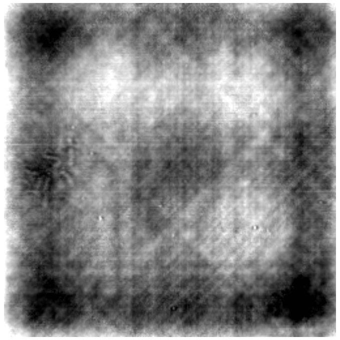
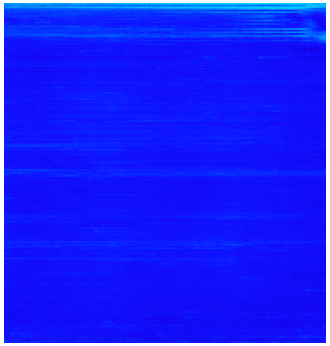
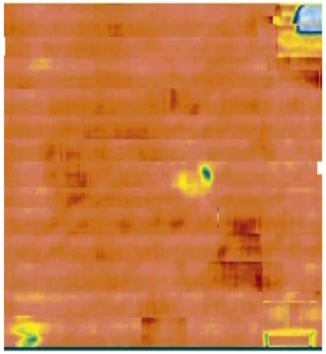


MAUS Resonance



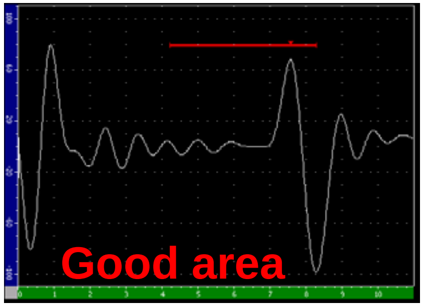
Omni PA

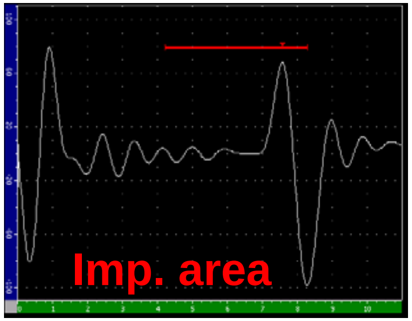


Ramp Damage Checker
(flaw indicated)

N

A-scan Ref





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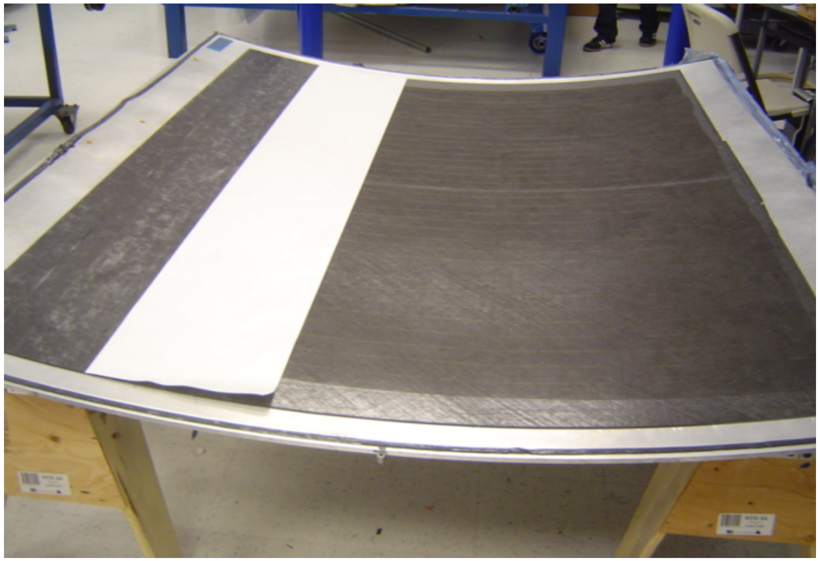
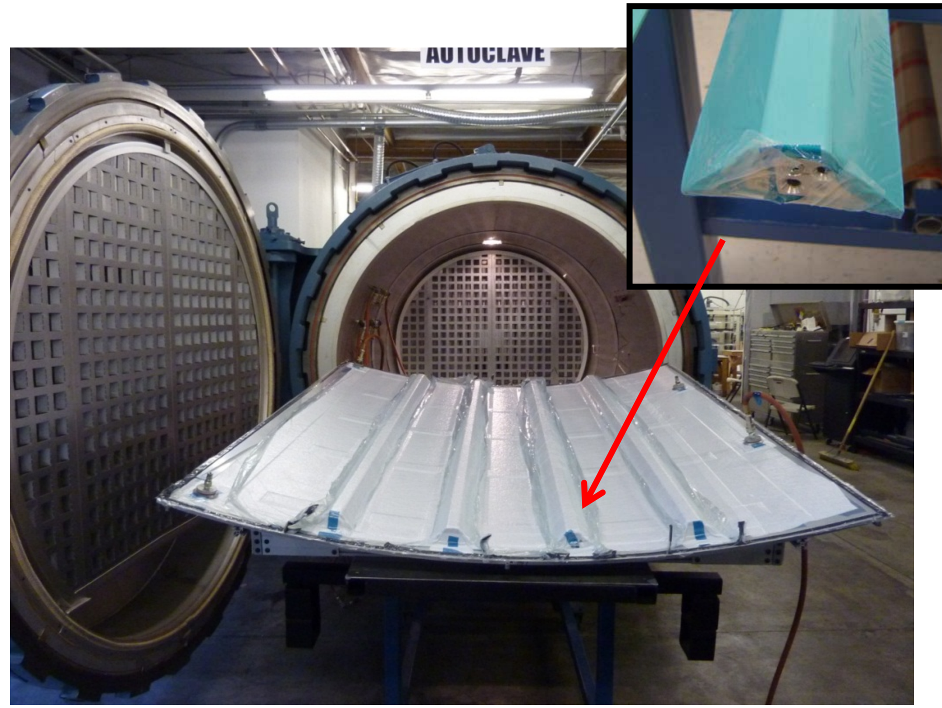
Full-Scale Fuselage Test Panel Fabrication

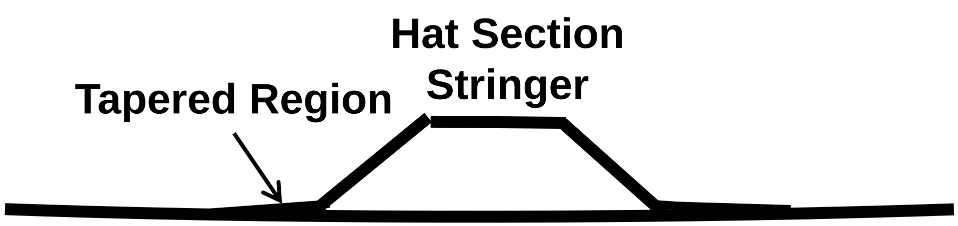
Not flat, simple structures



Skin - Curved Construction



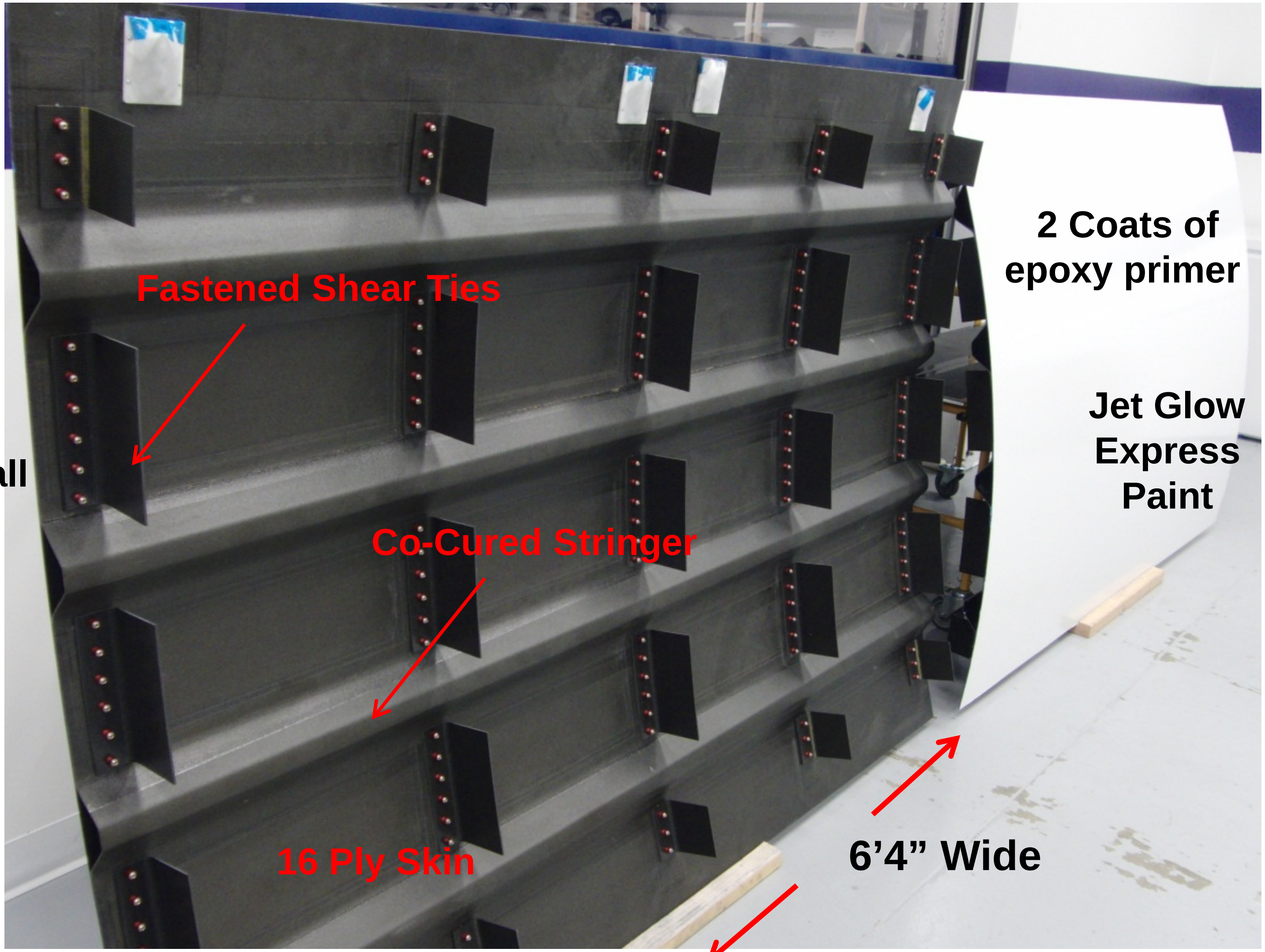
Autoclave Cured (350° F at 90 psi)



Quasi-Isotropic Lay Up $[0,+45,90.-45]_{2(s)}$

T800 unidirectional pre-preg tape with a 3900 series resin system (BMS8- 276)

Full-Scale Fuselage Test Panels



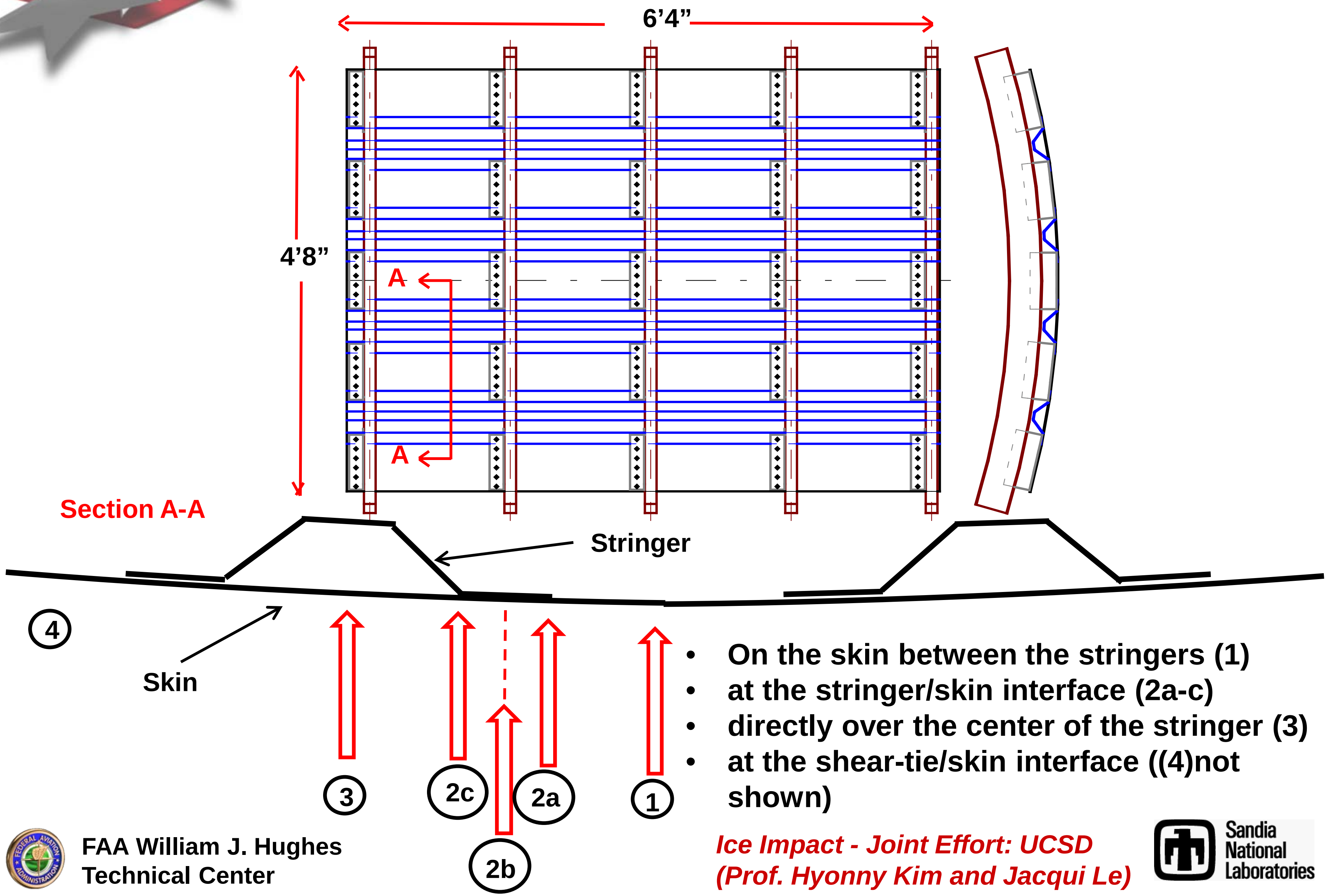
4'8" Tall

6'4" Wide

2 Coats of epoxy primer

Jet Glow Express Paint

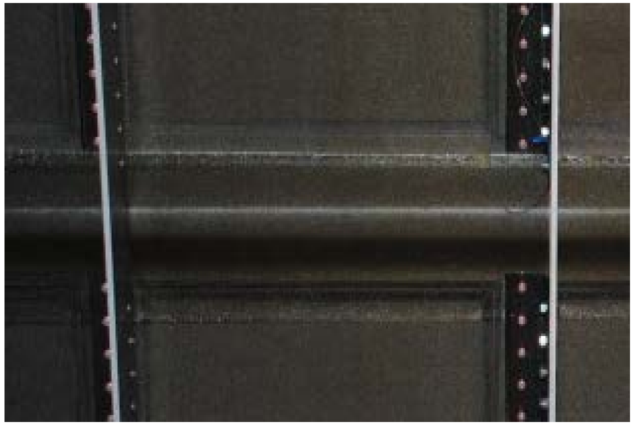
Impact Locations of Interest



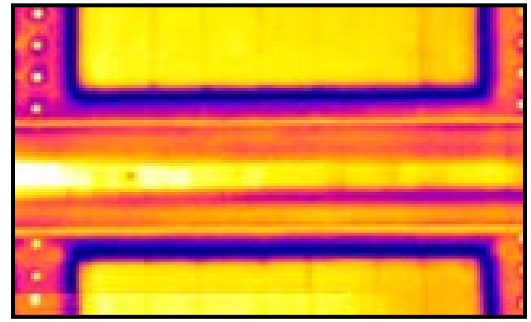
- On the skin between the stringers (1)
- at the stringer/skin interface (2a-c)
- directly over the center of the stringer (3)
- at the shear-tie/skin interface ((4)not shown)

Ice Impact - Joint Effort: UCSD (Prof. Hyonny Kim and Jacqui Le)

C-Scan Inspection Interpretation

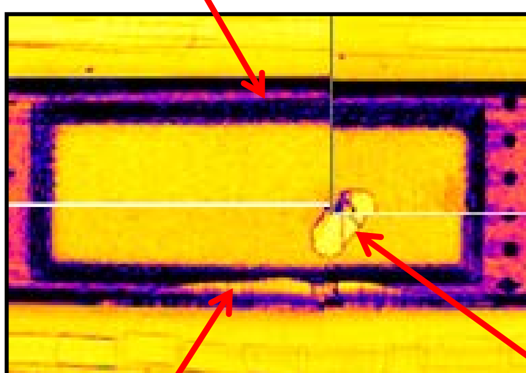


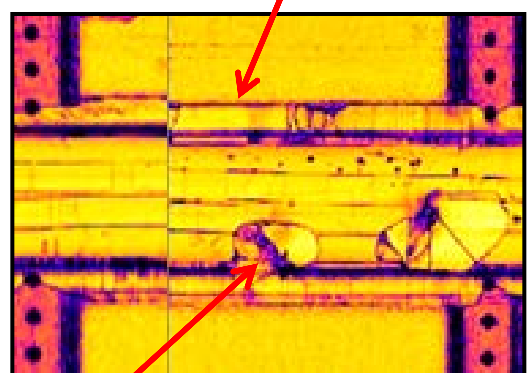
Pristine Area



Fully bonded stringer flange

Fully disbonded stringer flange

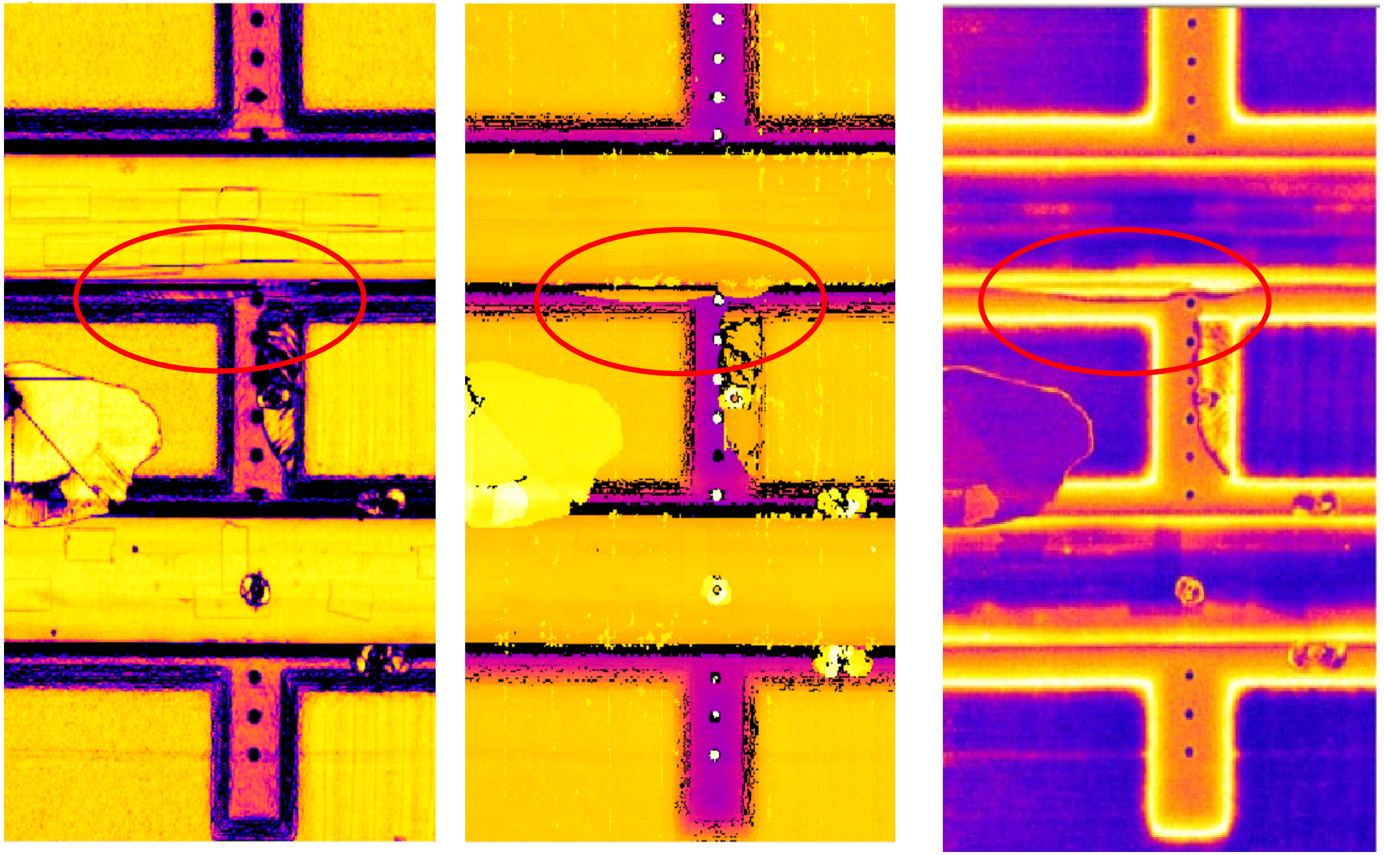




Partially delaminated stringer flange

Interply delamination in the skin

Comparison of NDI Techniques

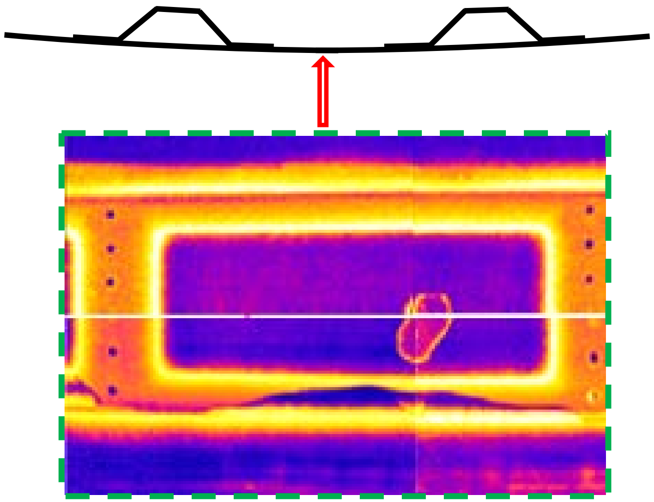


UT Amplitude | UT Time of Flight | UT Resonance

TOF and Resonance enhance detection of small disbonds

Ice Impact Testing Results

Mid-Bay Impacts



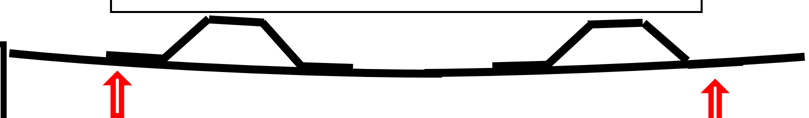
UT Resonance Y-Plot

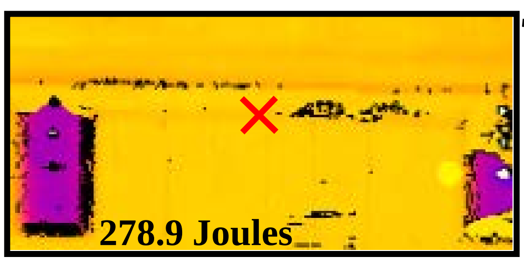
2.4 in diameter simulated hail impact tests were conducted between 50 and 120 m/s.

Terminal velocity ~ 30 to 35 m/s)

- Induce both interply delamination and substructure disbonding
- No damage was visually detectable from the surface
- Damage was initiated at approximately 230 Joules (~67 m/s)

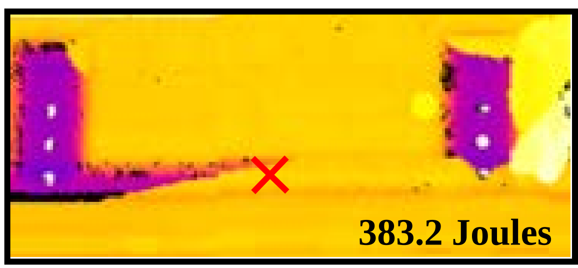
Stringer Flange Impacts





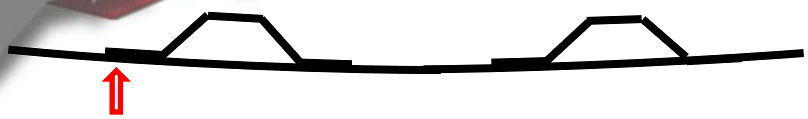
(0.0) / (23.16)

- Induce only substructure flange disbonding
- No damage was visually detectable from the surface
- Damage was initiated at approximately 170 Joules (~56 m/s)



(0.0) / (16.09)

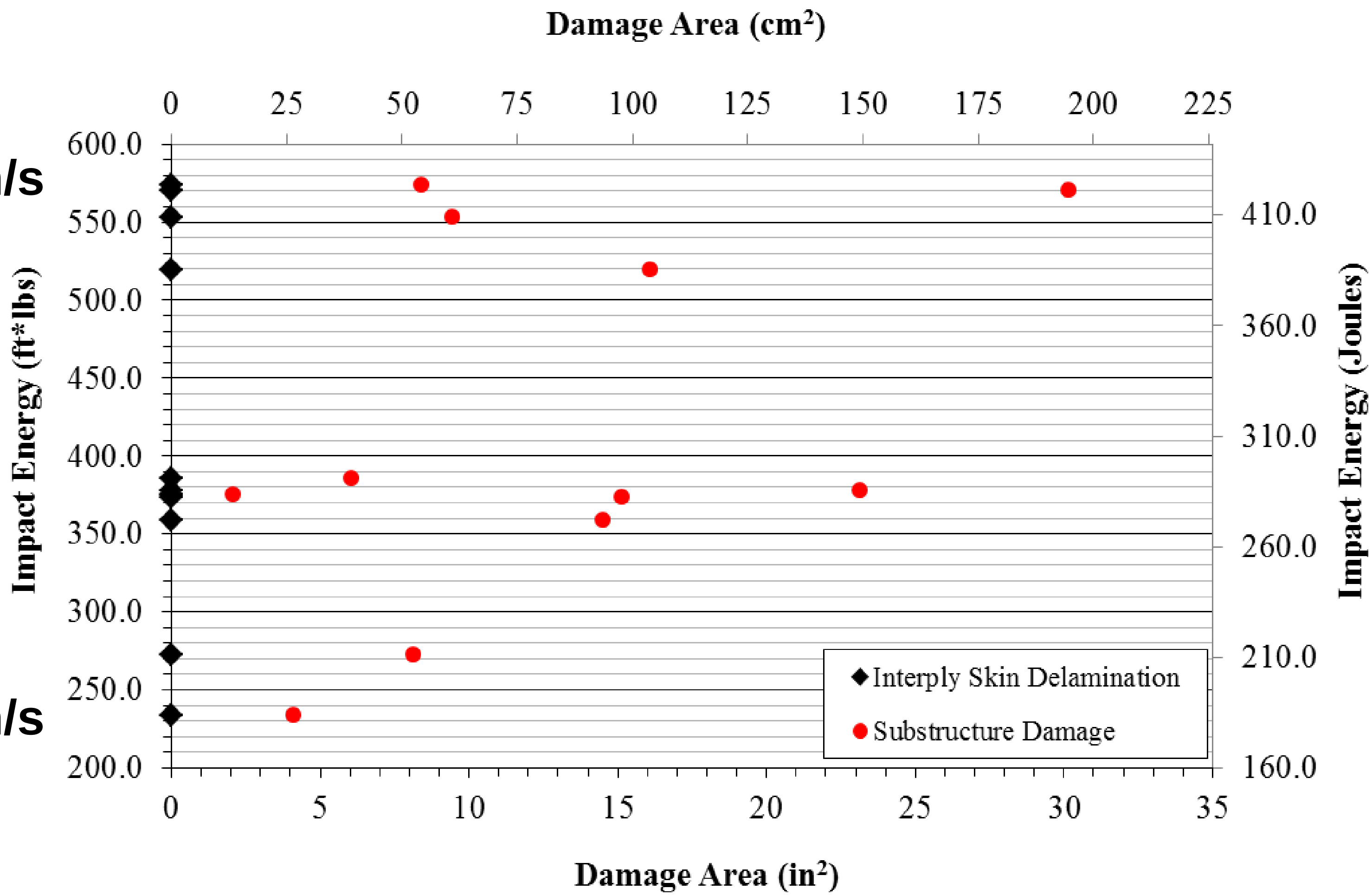
Ice Impact Testing Results



Stringer Flange Impacts

89 m/s

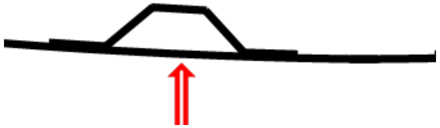
56 m/s

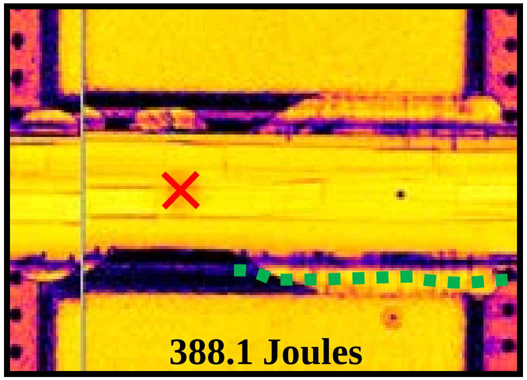


Initiated substructure disbonding only, no interply delamination detected with these impacts

Ice Impact Testing Results

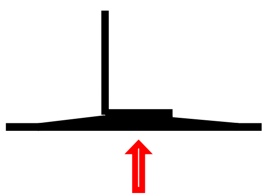
Mid-Stringer Impacts





- Induce both interply delamination and substructure disbonding (mostly flange disbonding)
- No damage was visually detectable from the surface
- Possible to initiate damage at less than 400 Joules

Shear Tie Impacts



- Induce built-up pad section delamination and cracked shear ties
- Damage was visually detectable from the surface (cracks, surface markings at approximately 700 Joules (115 m/s))

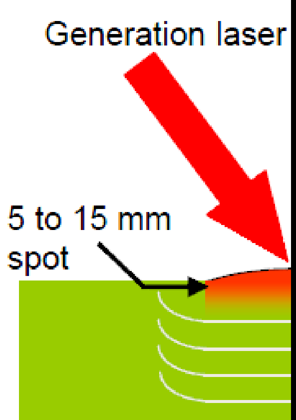
All shear tie impacts cracked the impacted shear tie

iPhoton Solutions Full Panel Inspection Results

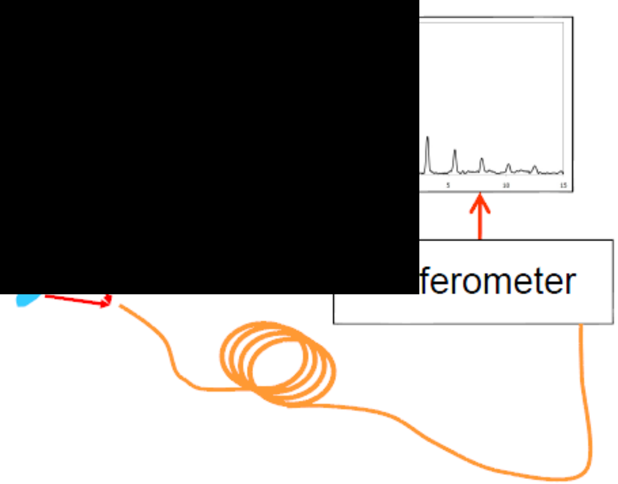
iPhoton

- Laser-ultras[redacted]
- Conventiona[redacted]
- High speed [redacted]
- Uses comm[redacted]

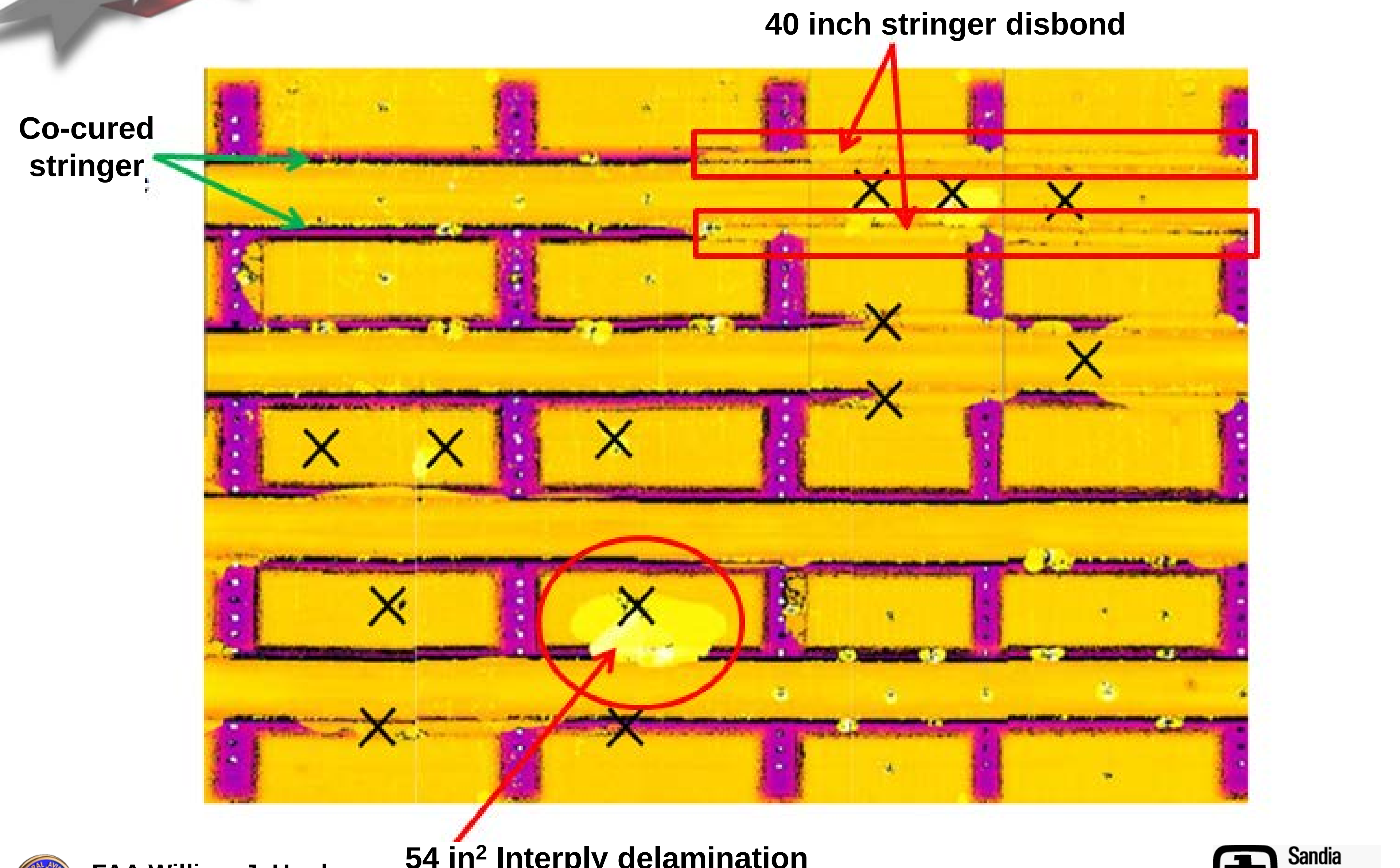
[redacted]cted
[redacted] and



[redacted]



Significant Damage with No Visual Indication



Conclusion

- **AANC Composite Impact Studies Include:**
  - ➢Identifying impact scenarios of concern
  - ➢Identifying key parameters governing impact damage
  - ➢Characterizing impact damage below the BVID level
  - ➢Relating damage threat to capabilities of NDI
- **NDI ability** to detect impact damage was assessed in FTE ~ BVID range → sensitivity, sizing, procedures, deployment

The presented work shows that...

- This structure is robust against hail impact
- Large damage can occur with no surface visual indication
- Impacts can initiate substructure damage away from the impact site
- Substructure impacts induce damage at less energy than mid-bay impacts
- Hard tip impacts induce localized, near surface damage that are typically visibly detectable from the surface (depends on tip diameter and hardness)

Ongoing efforts...

- Subsurface damage can be difficult to detect with conventional NDI (ref. AANC SLE POD)
- Characterized panels are being used to assess emerging NDI technologies

Sponsors and Collaborators

Thanks to our sponsors and collaborators

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- **Rusty Jones – FAA**

- **Professor Hyonny Kim – UC San Diego**
- **Jacqui Lee – UC San Diego**