Inspection Options for Detecting Various Types of Impact Damage in Composite Structures

SAND2013-7877C

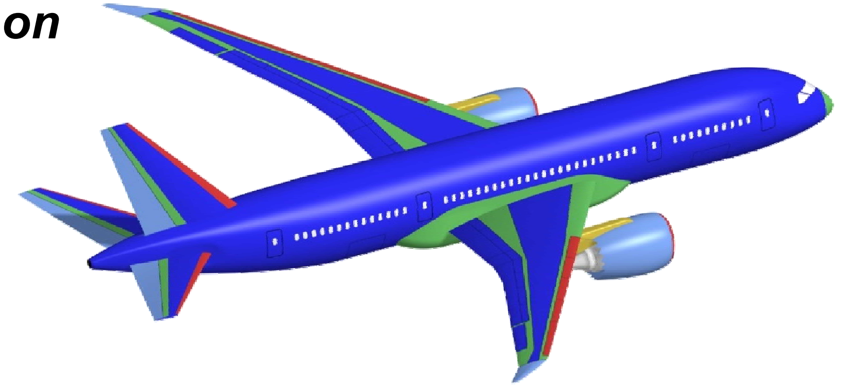
Dennis Roach, Stephen Neidigk,
Tom Rice, Randy Duvall
Sandia National Labs
FAA Airworthiness Assurance Center

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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



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

FAA William J. Hughes
Technical Center

Sandia National Laboratories

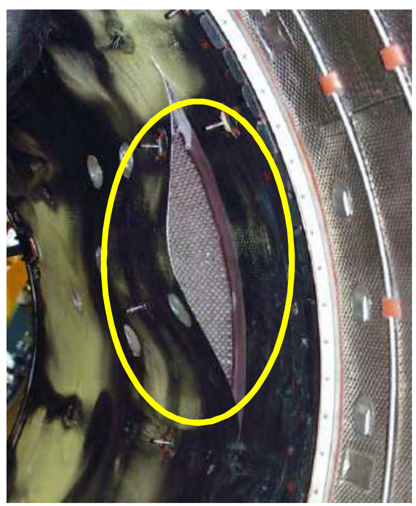
Sources of Damage in Composite Structure

One airline reports 8 composite damage events per aircraft (on avg.) with 87% from impact; cost = $200K/aircraft

Lightning Strike on Thrust Reverser

Bird Strike

Towing Damage



Disbonding at skin-to-honeycomb interface

AANC Composite Programs
(CACRC Inspection Task Group Guidance)

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

- Composite Impact Study
  - 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

Blunt – high mass, low velocity
Sharp - low mass, high energy

ITG Team Participants

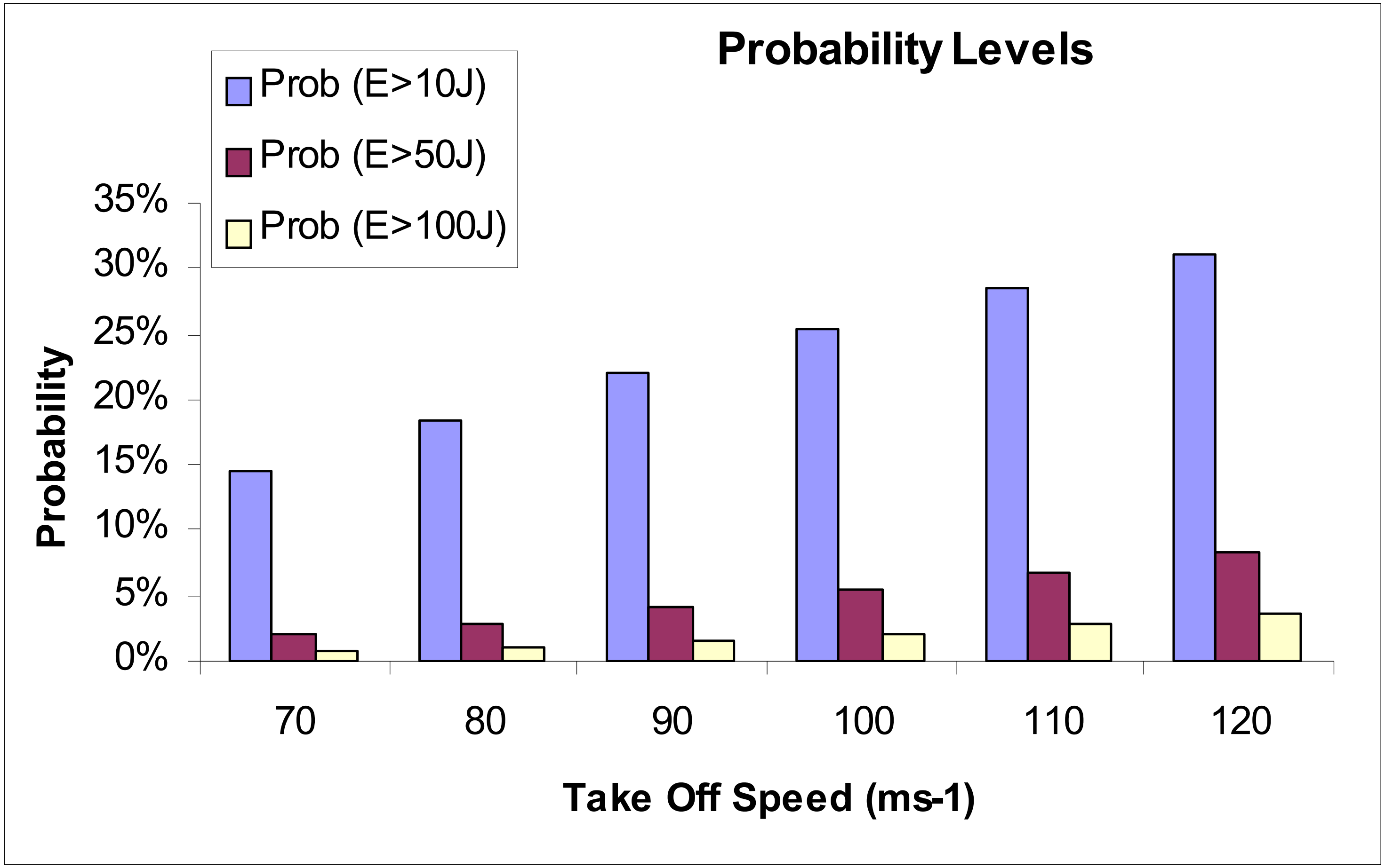
CACRC Inspection Task Group Members:

Keith Phillips – Airbus
Jim Hofer – Boeing
Jeff Kollgaard – Boeing
Kirk Rackow – Sandia Labs AANC
Dennis Roach – Sandia Labs AANC (Chair)
Glae McDonald – US Airways
Darrell Thornton – UPS
Richard Watkins – Delta Air Lines
Eric Bartoletti – American Airlines
Alex Melton – Delta Air Airlines
Ana Tocalino – Embraer
Quincy Howard – Boeing
Chris Dragan – Polish Air Force Institute of Technology
Robert Luiten – KLM Airlines

Dave Galella, Paul Swindell, Al Broz, Rusty Jones, Larry Ilcewicz – FAA

Probability of Impact Energy as a Function of Take-Off Speed

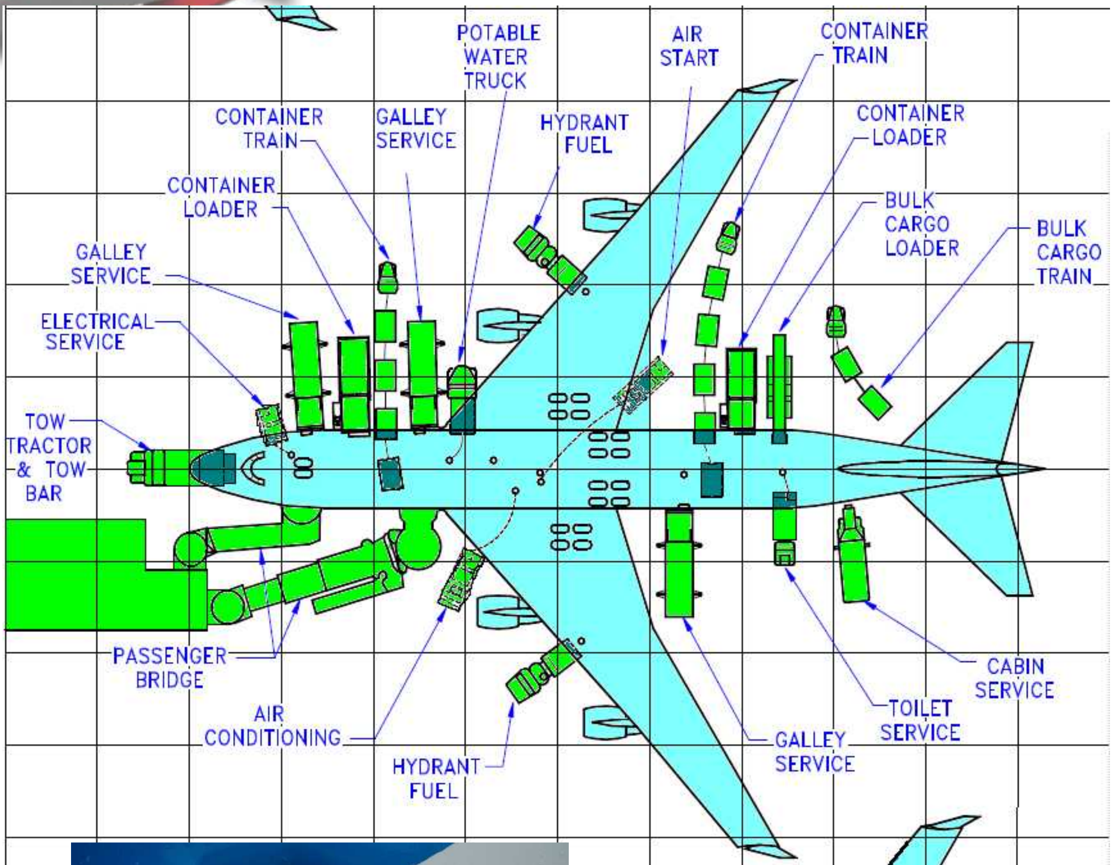
(based on runway debris collected from 4 UK military air bases)

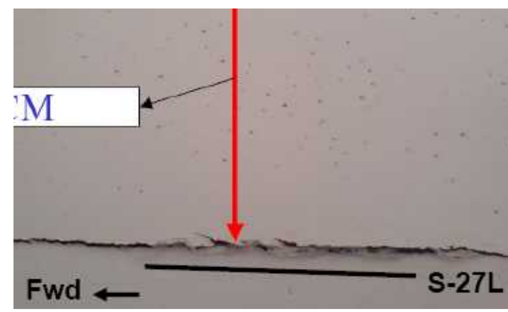


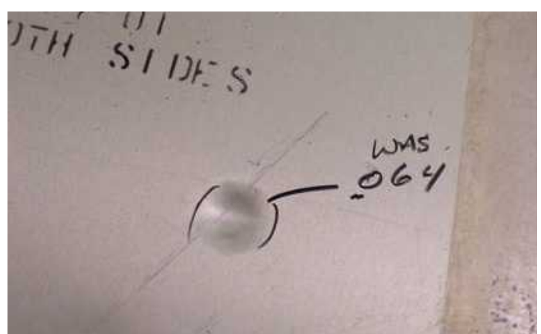
Typical Runway Debris

Source: Prof Paul Curtis, DERA/MSMA2/TR000702

Blunt Impact Threat from Ground Support Equipment



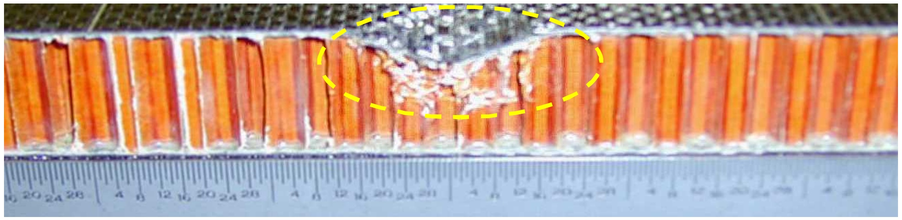




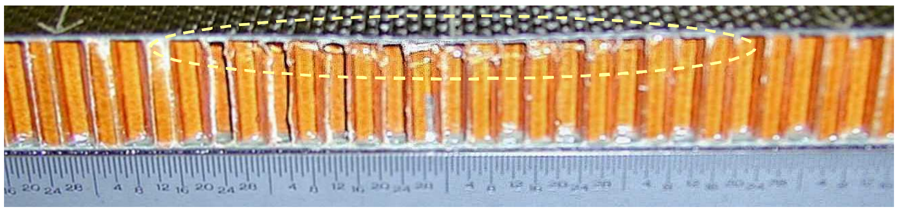
Damage may be less obvious in composites than in metallic structures

Inspection Challenge – Hidden Impact Damage

Backside fiber failure from ice impact

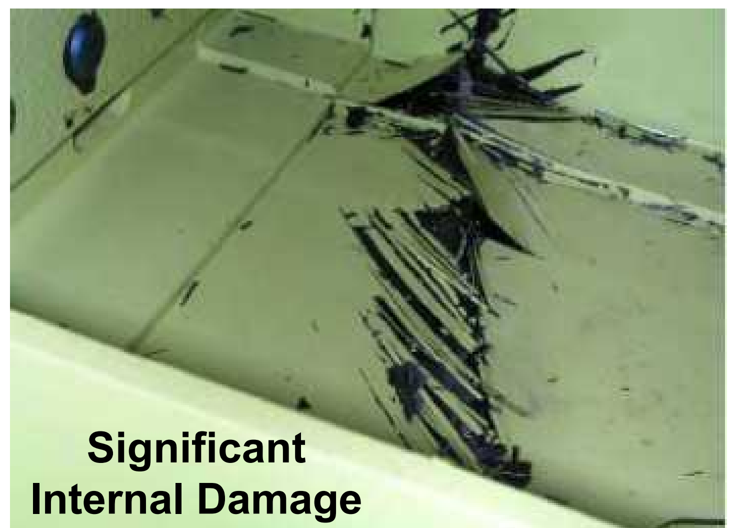


Visible Impact Damage – external skin fracture



Backside Damage – internal skin fracture & core crush

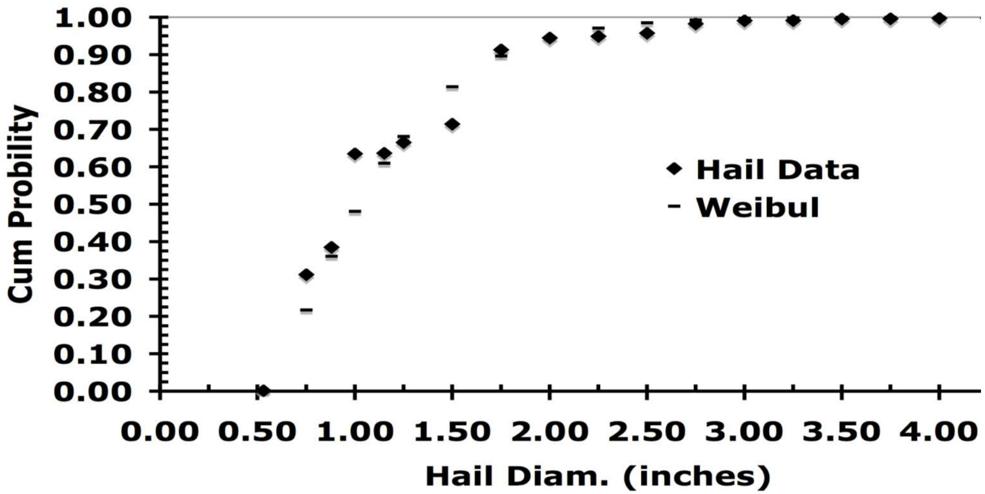
Damage from ground vehicle



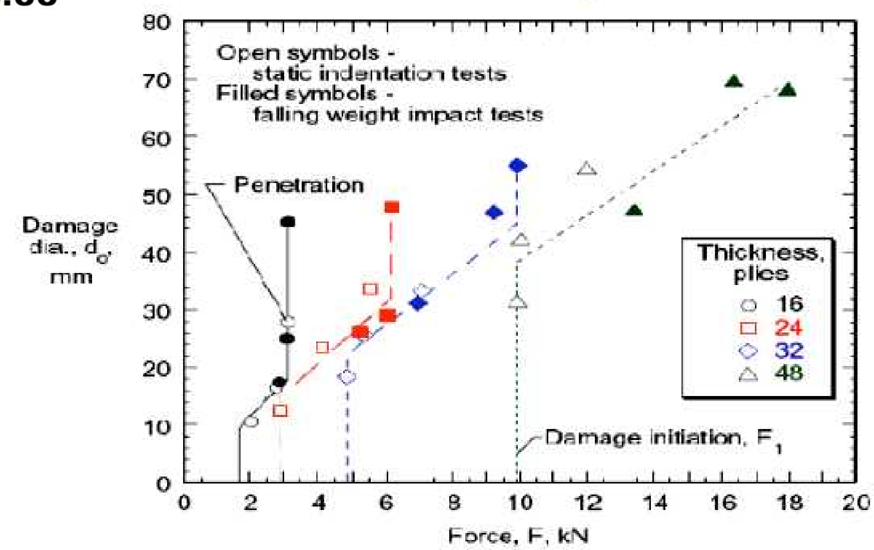
Source: Carlos Bloom (Lufthansa) & S. Waite (EASA)

Impact Damage Formation & Inspection in Composite Aircraft Structures

Joint Effort: UCSD (Hyonny Kim)



- Damage thresholds vs. laminate design; allowable limit
- Threat environment
- Inspection for cause – self evident event vs. self evident damage



Damage size from onset to laminate penetration

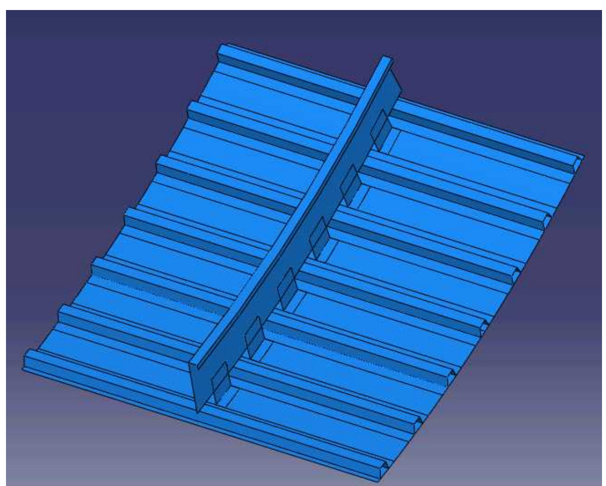
FAA William J. Hughes Technical Center

Sandia National Laboratories

Composite Impact Study - Background

- **Identify key phenomena that govern impact damage (model) & relate them to damage initiation**
- **Correlate global (mass, structure, velocity) and local (contact stiffness, angle) parameters to assess threat level of an impact event → aid maintenance decisions**
  - ➢ **Panel geometry/design, impact energy & orientations, material of impactor (metals, bumpers, ice)**
  - ➢ **Visual detectability related to damage (generation of surface markings)**

Composite skin with substructure



Low velocity, blunt impact

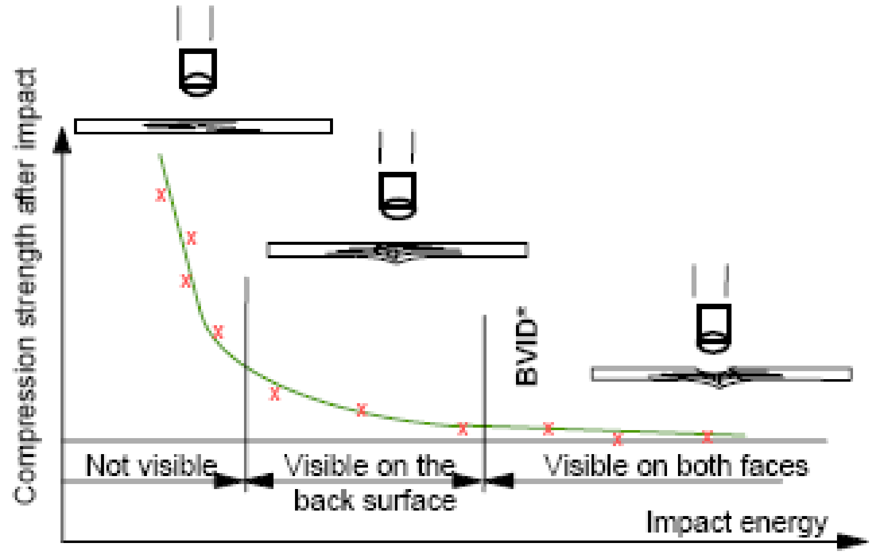
Composite Impact Study – Hail Impact Task Description

- **112 carbon composite panels were fabricated using BMS8-276N uniaxial material; consisted of 8, 16, and 24 ply configurations (12” x 12”)**
- **All panels are being 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**

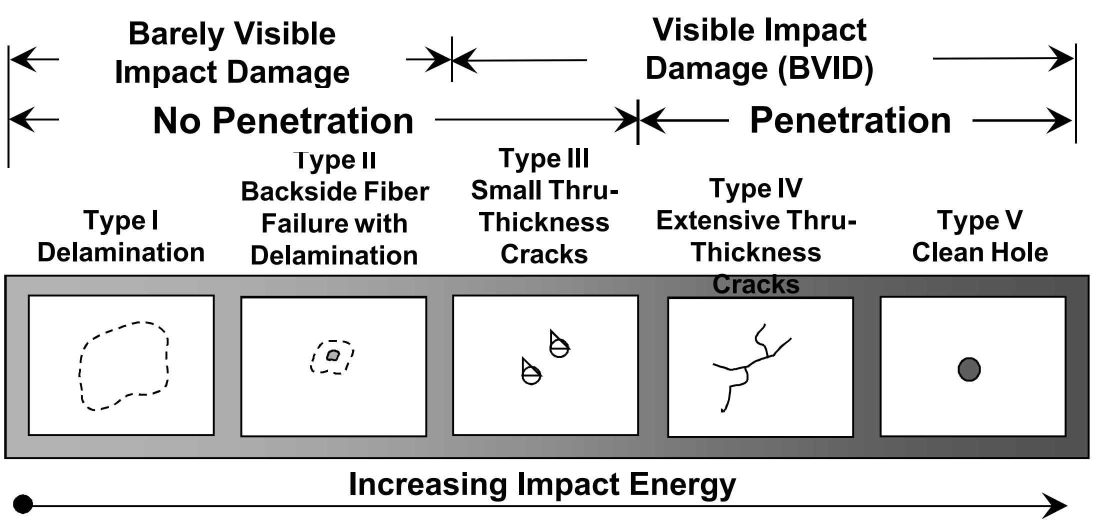
Hail Ice Impact
- upward & forward facing surfaces
- low mass, high velocity

Effects of Impact on Composite Structures

Challenge: hidden damage in composite structures can be difficult to detect visually and/or require special trained technicians and special equipment to be detected



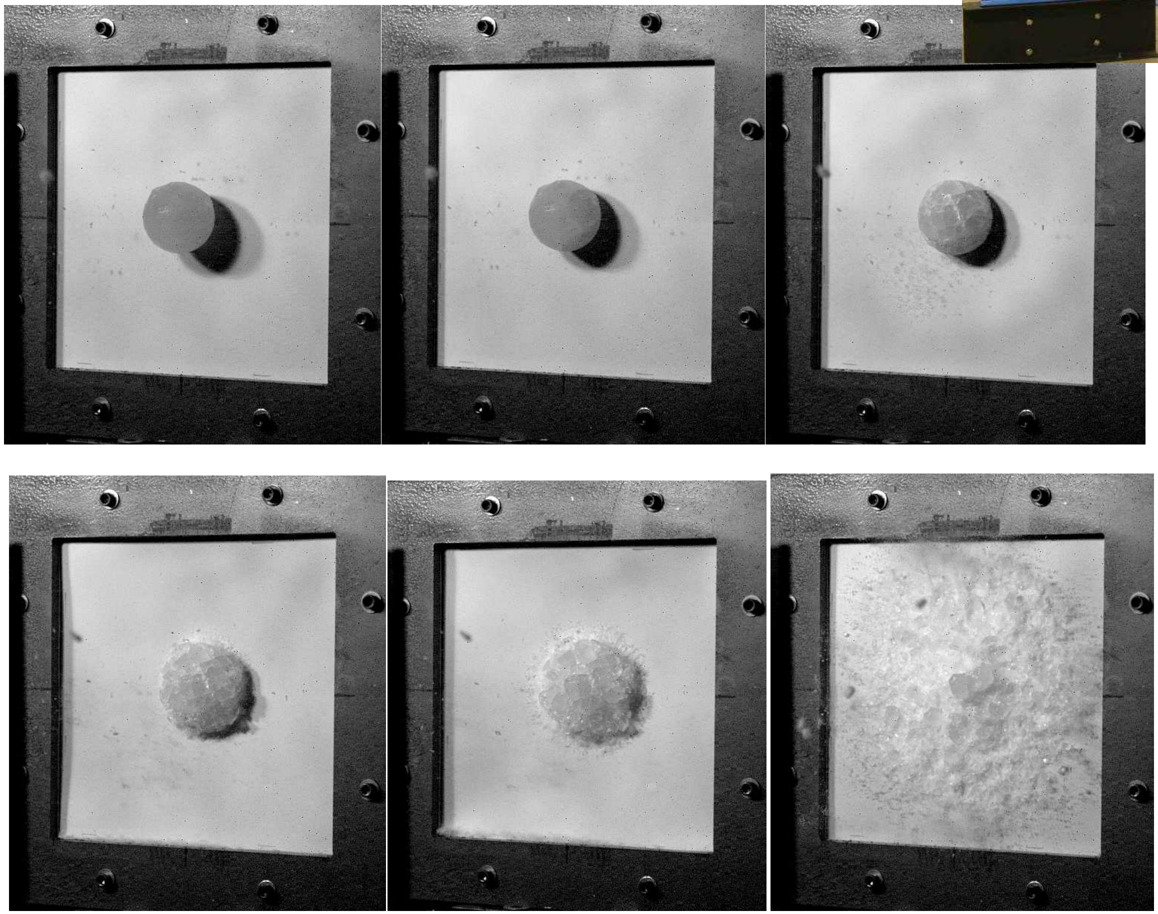
* BVID = Barely Visible Impact Damage



Backside fiber failure from ice impact

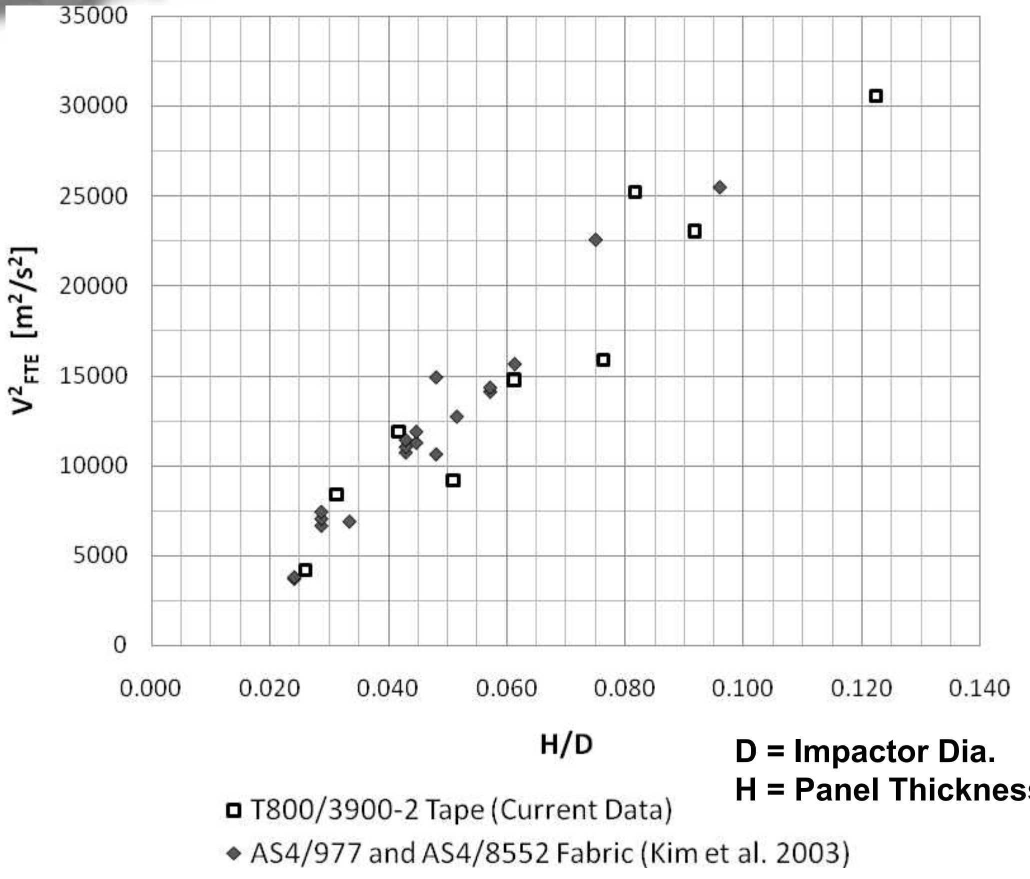
Ice Impact at UCSD

UCSD High Velocity Gas Gun

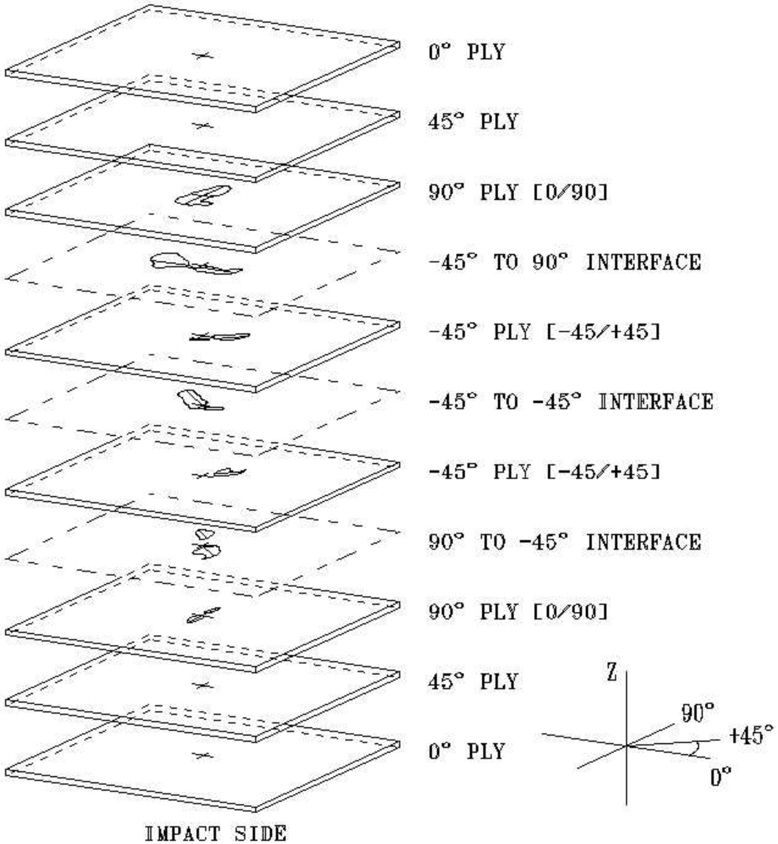


Still Images from 61 mm Ice Impact on 8 Ply Carbon Panel at 72 m/s

Damage in Composite Laminates from Ice Impact



D = Impactor Dia.
H = Panel Thickness



Failure Threshold (Energy) Velocity

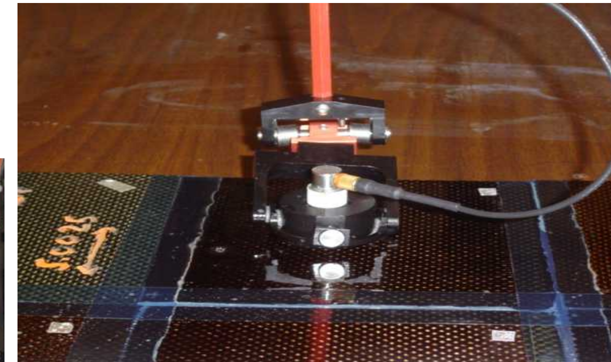
Impact-Induced Damage Morphology for 8 Ply Panel; 42.7 mm Ice at 120.4 m/s (267 J)

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

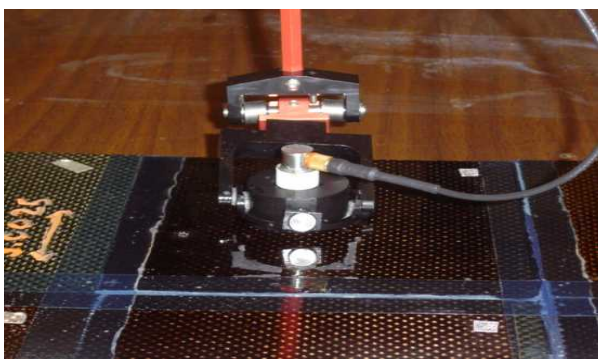
Composite Impact Damage – Inspection Methods Deployed

TTU

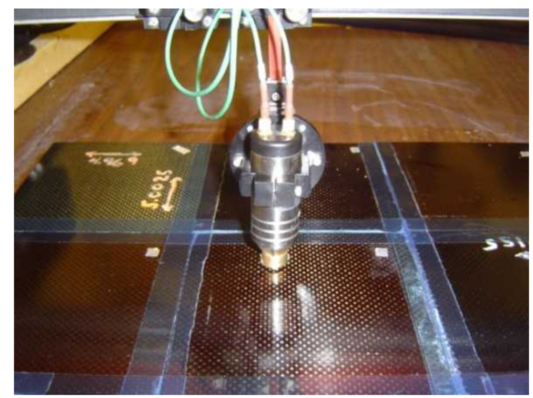
Thermography



MAUS PE



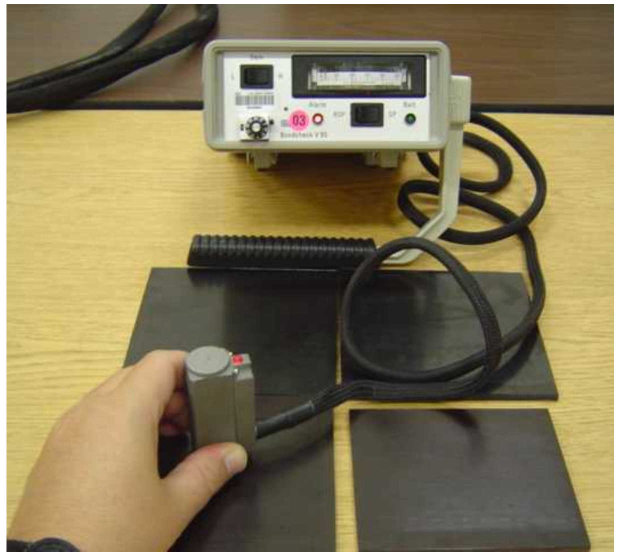
MAUS Resonance



MAUS MIA

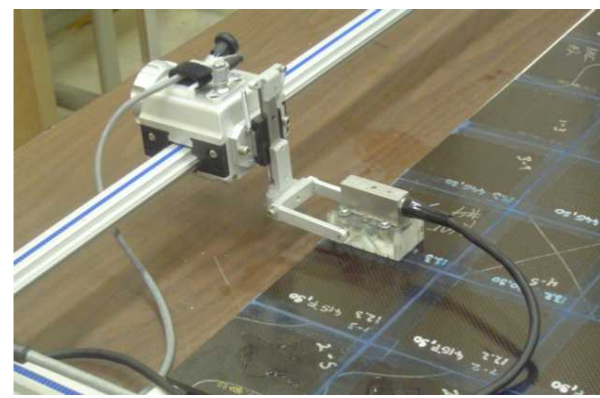
Composite Impact Damage – Inspection Methods Deployed

Damage Check Device
(Pulse-Echo UT)



V-95
(Mechanical Impedance
Analysis)

MAUS LFBT



Omniscan Phased Array UT

TC-8-06

Impact Energy (J) - 328

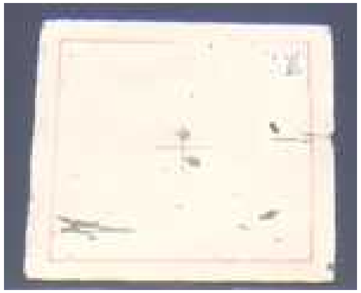
Impact Velocity (m/s) - 78

Projectile Size (mm) - 61.0

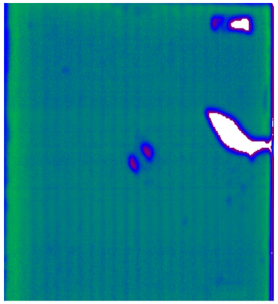
Flaw Size SNL/UCSD (mm^2) - 1,122/n/a

Flaw Size (major/minor dia. in mm) - 41.4/34.5

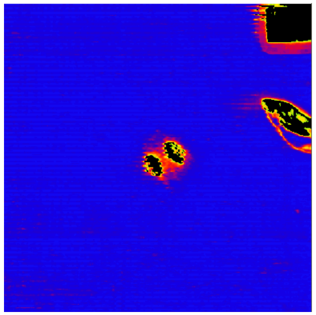
Picture



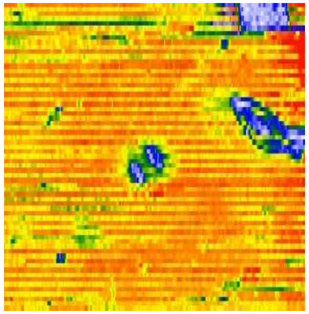
TTU



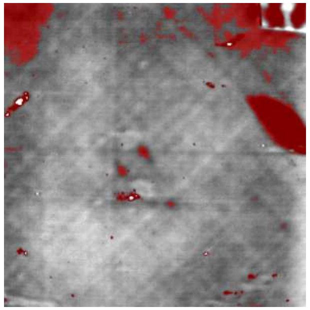
MAUS PE



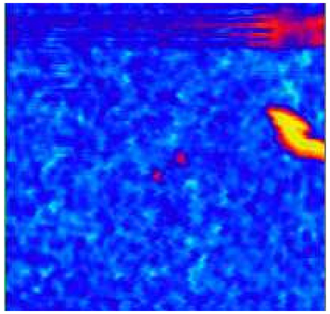
Omni PE



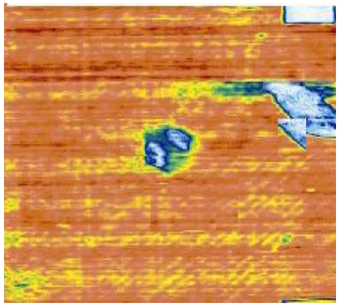
IR



MAUS Resonance



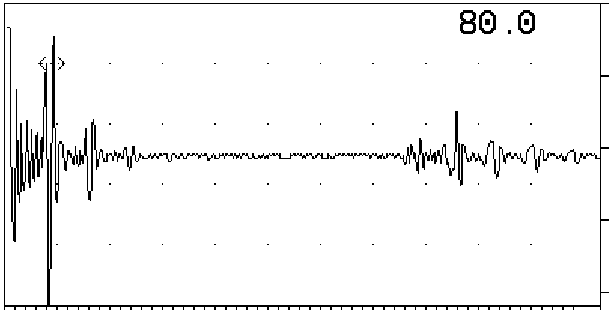
Omni PA



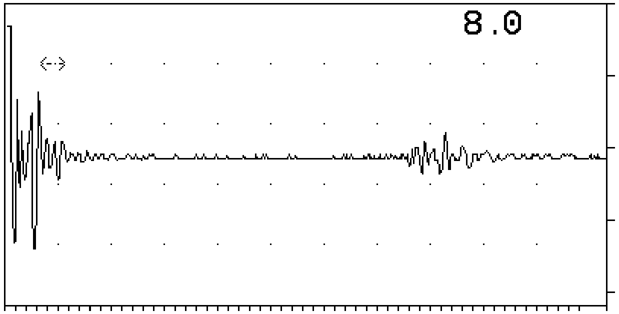
Damage Check (flaw indicated)

Y

A-scan Ref



A-scan Flaw



TC-16-04

Impact Energy (J) - 203, 271, 302

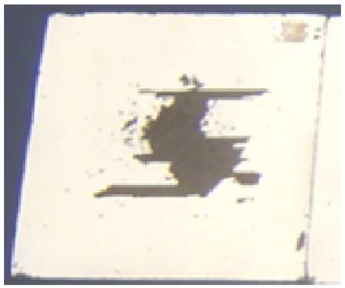
Impact Velocity (m/s) - 129, 146, 157

Projectile Size (mm) - 38.1

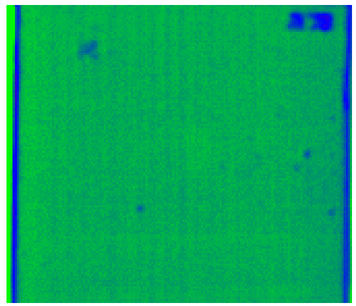
Flaw Size SNL/UCSD (mm²) - 1,420/0

Flaw Size (major/minor dia. in mm) - 46.5/38.9

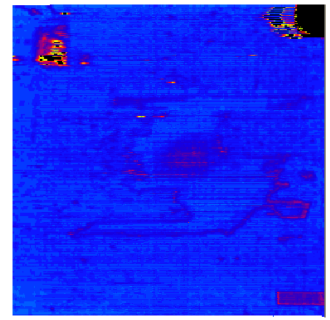
Picture



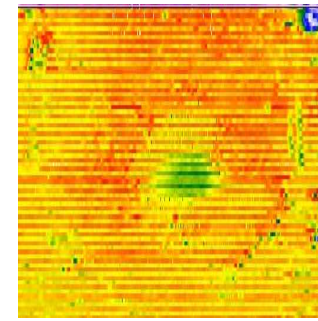
TTU



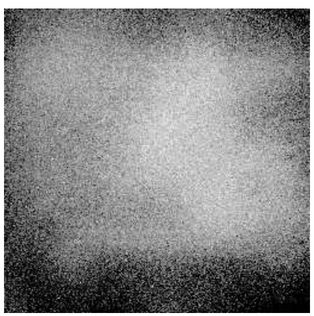
MAUS PE



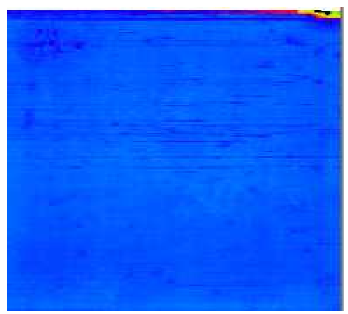
Omni PE



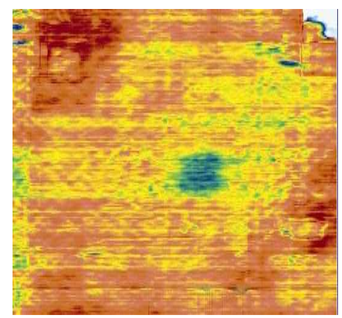
IR



MAUS Resonance



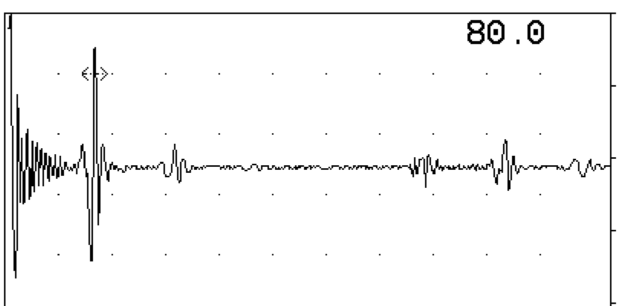
Omni PA



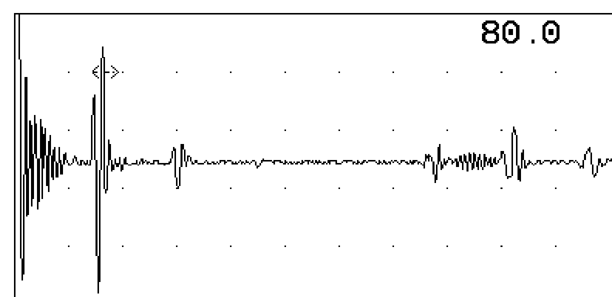
Damage Check (no flaw indicated)

N

A-scan Ref



A-scan Flaw



FAA Willia
Technical

TC-16-06

Impact Energy (J) - 332

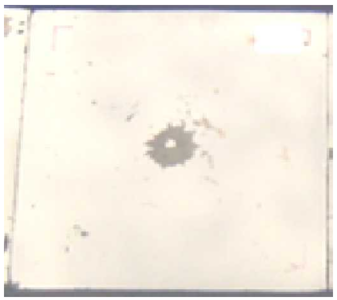
Impact Velocity (m/s) - 162

Projectile Size (mm) - 38.1

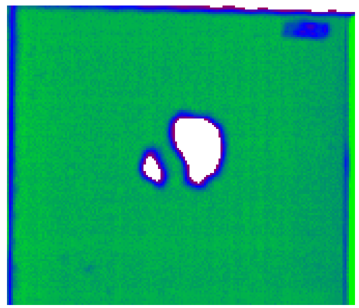
Flaw Size SNL/UCSD (mm²) - 5,460/2768

Flaw Size (major/minor dia. in mm) - 85.3/81.5

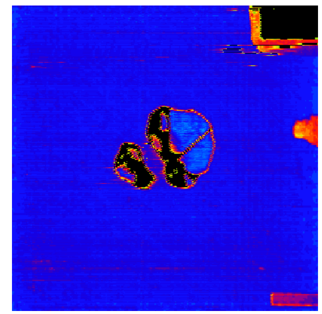
Picture



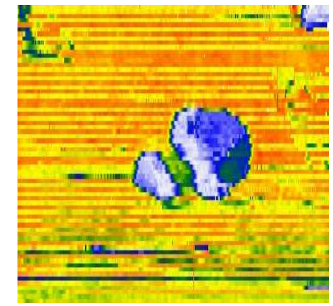
TTU



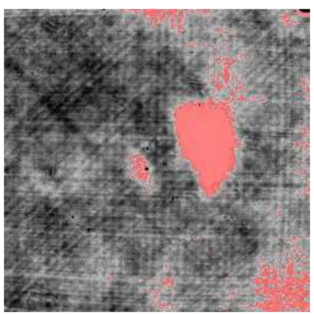
MAUS PE



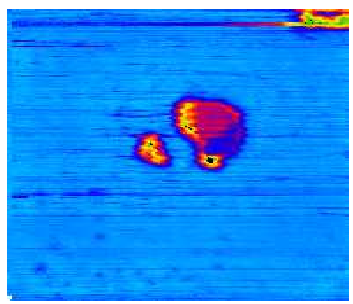
Omni PE



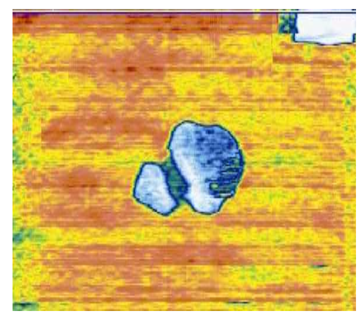
IR



MAUS Resonance



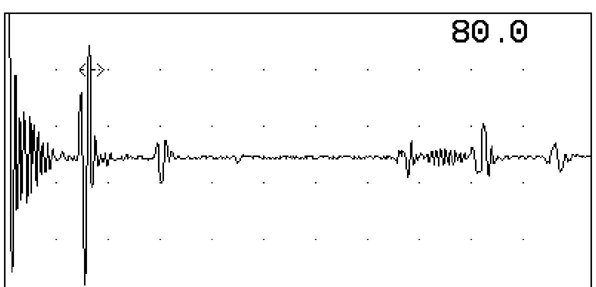
Omni PA



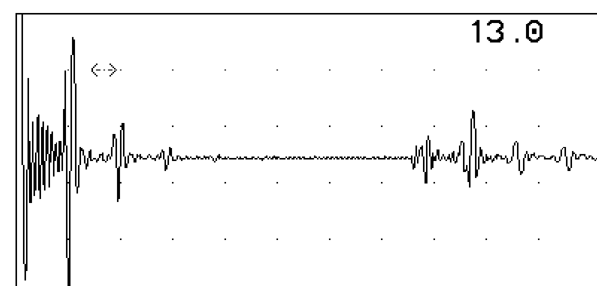
Damage Check (flaw indicated)

Y

A-scan Ref



A-scan Flaw



Impact Damage Program Inspection Results from 24 Ply Panel

TC-24-11

Impact Energy (J)- 704 & 819

Flaw Size MAUS PE (mm^2) - 8708

Flaw Size Omniscan PE (mm^2) - 9030

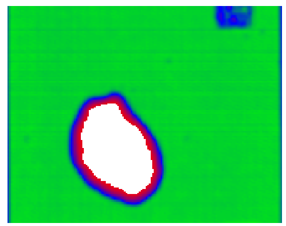
Flaw Size TTU UCSD (mm^2) - n/a

Impact Velocity (m/s) - 151 & 163

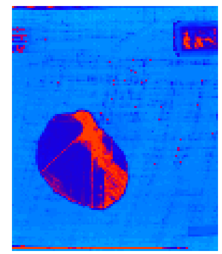
Projectile Size (mm)- 50.8

Picture

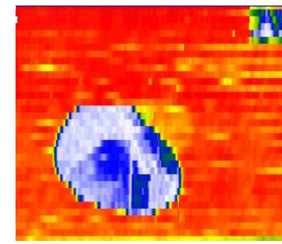
TTU



MAUS PE

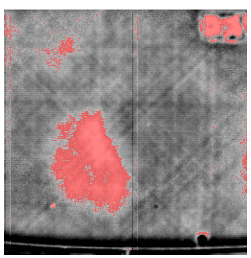


Omni PE

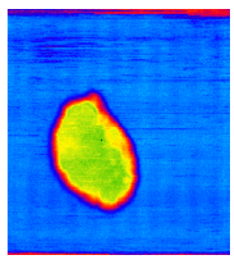


Large damage area

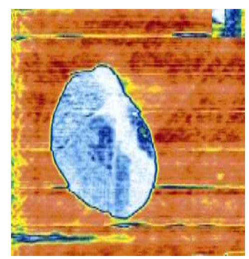
IR



MAUS Resonance



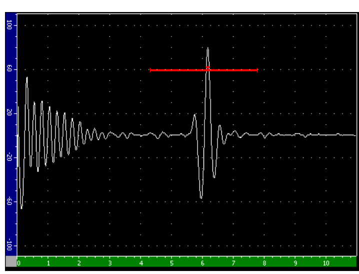
Omni PA



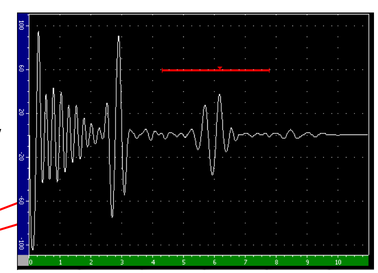
Damage Check (flaw indicated)

Y

A-scan Ref



A-scan Flaw



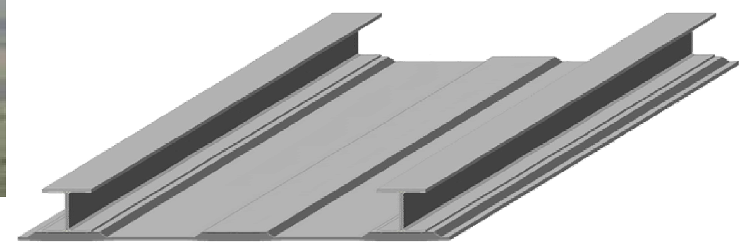
Notice loss of backwall signal and new intermediate signal

FAA William J. Hughes Technical Center

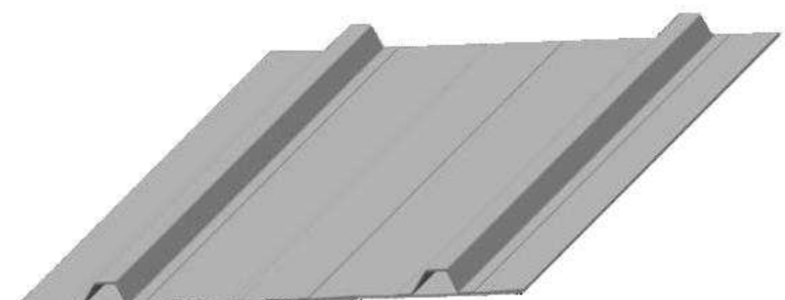
Sandia National Laboratories

Image Based NDE for Modern Rotorcraft Sustainment – Composite Inspection of Solid Laminate Structures

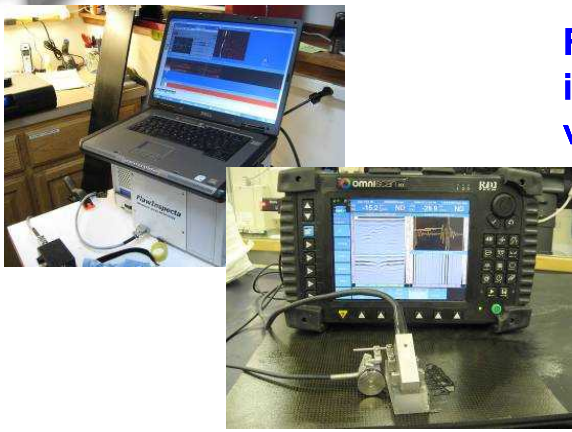
- Support for Bell Helicopter BAA
- Detect and characterize impact damage in full-scale panels
- Impact energies range from 25 to 500 in-lb
- Fast, low-cost, large-area inspection methods – visual based displays
- Screening NDI (“go” – “no go”) for ramp personnel (minimal training)



Full-Scale Panel Designs

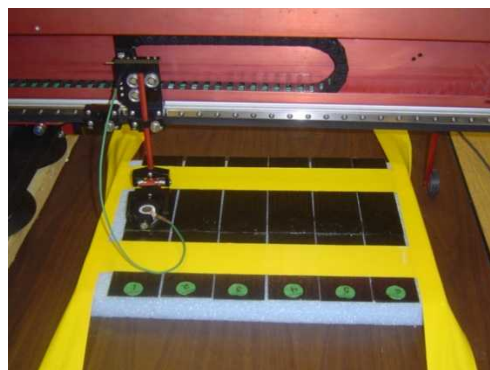


Bell Helicopter – Composite Inspection of Solid Laminate Structures

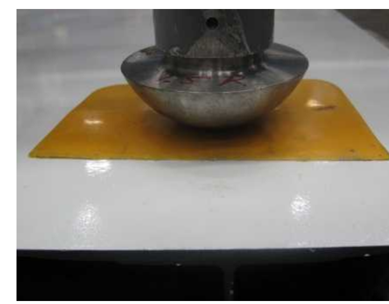


Phased Array Ultrasonic Imaging (PAUT)

Field deployable infrared imaging (FDIR) to enhance visual inspections



MAUS PE UT, Resonance; Hand-Held PE UT

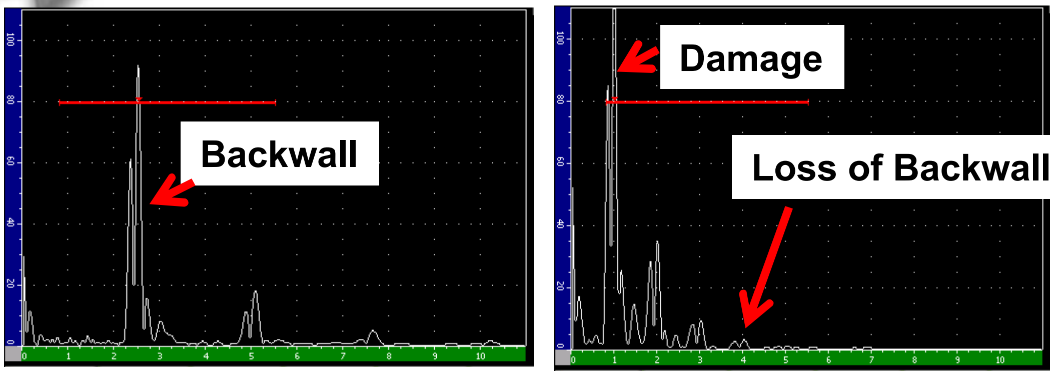


Impact Device

Digital Acoustic Video (DAV)

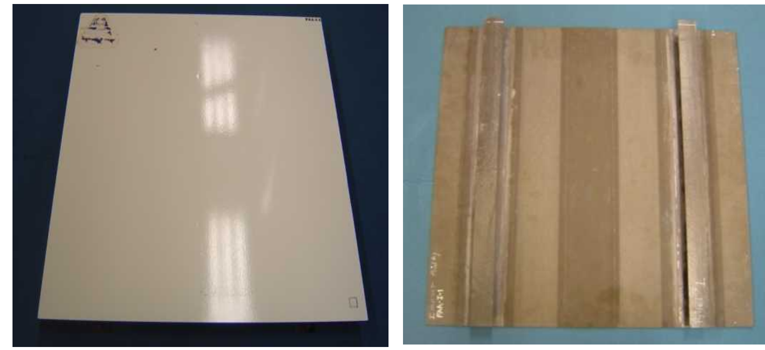
Olympus Damage Checker

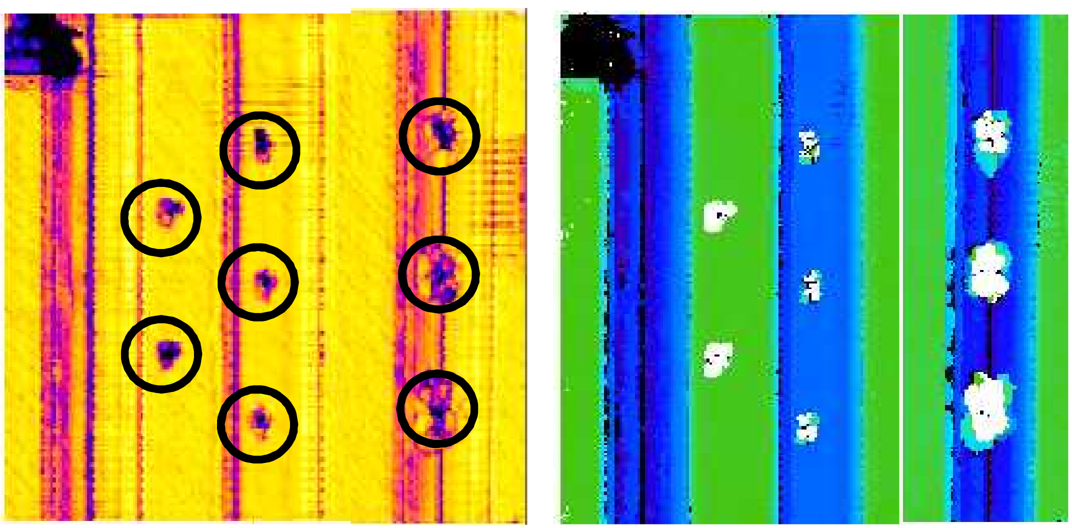
Bell Helicopter – Composite Inspection of Solid Laminate Structures



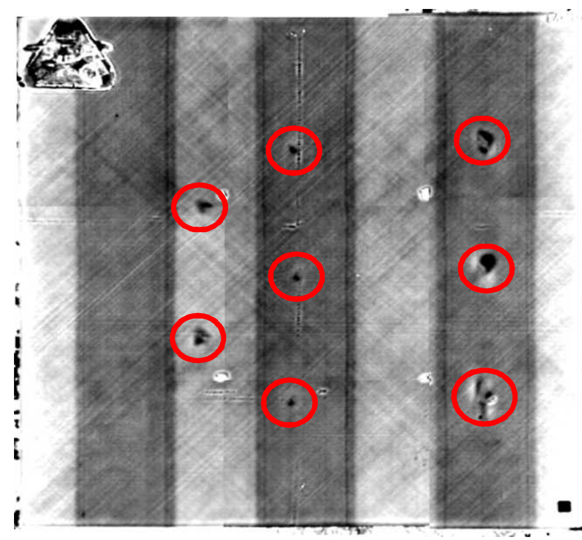
Assessment of A-Scan Signals in Real Damage

I-Beam Stiffened Panel FAA-I-1



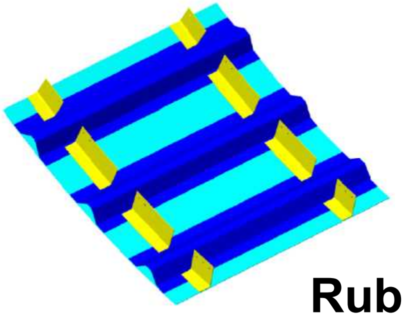


MAUS PE UT Amp & Tof F C-Scan Images

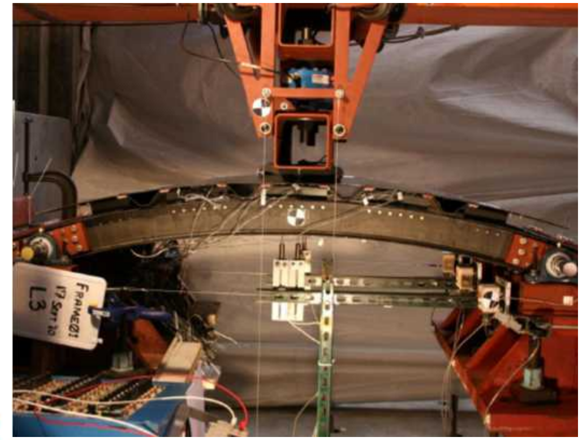


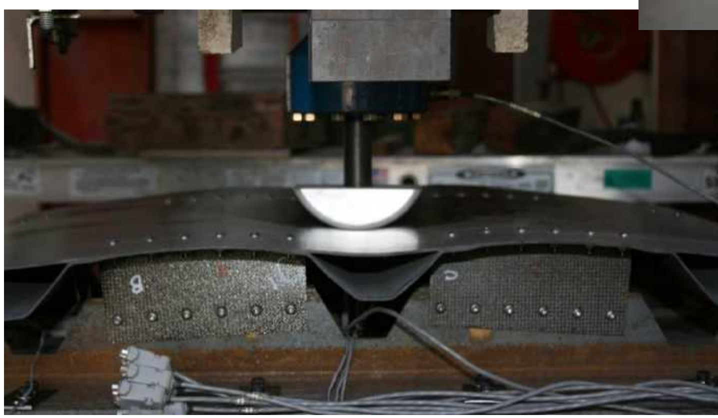
Flash Thermography Image

Impact Damage Program - Inspection of Full Scale Panels with Low Velocity-High Mass Impacts

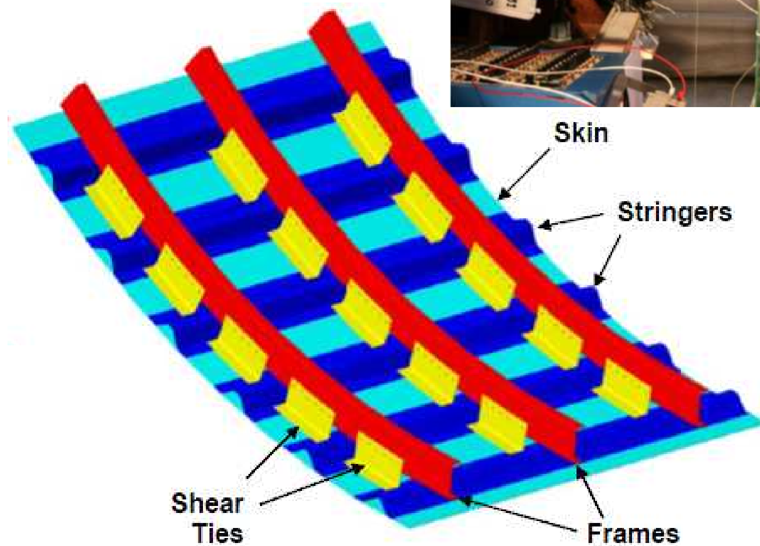


Rubber Bumper from Baggage Loading Cart





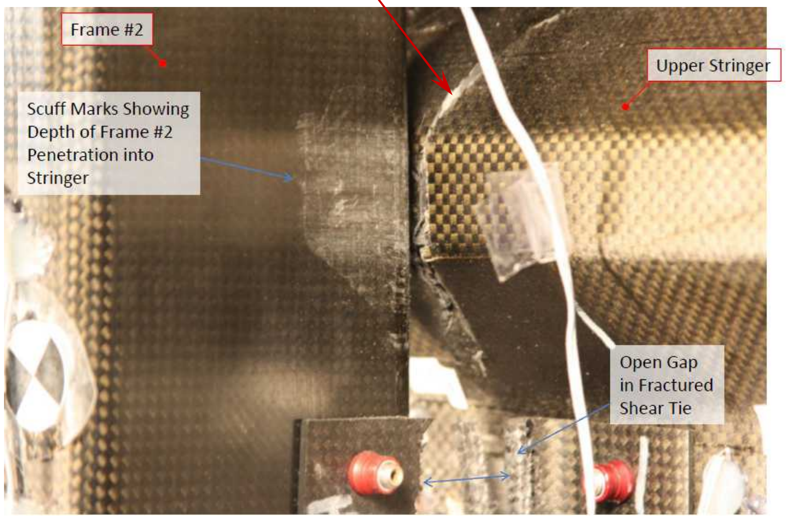
2' X 3' and 4' X 6' Panels With Substructure Elements



Wide area blunt impact – internal, distributed damage; high interlaminar shear & failure of co-cured joints

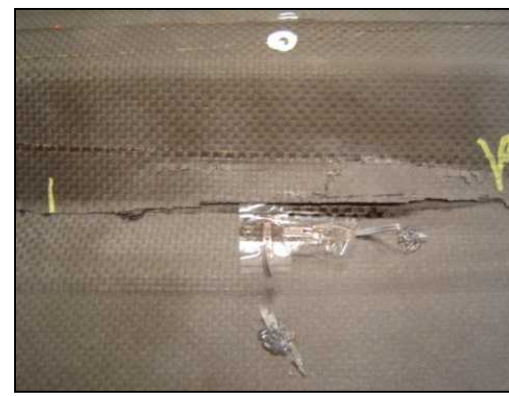
Inspection of Full Scale Panels with Low Velocity-High Mass Impacts

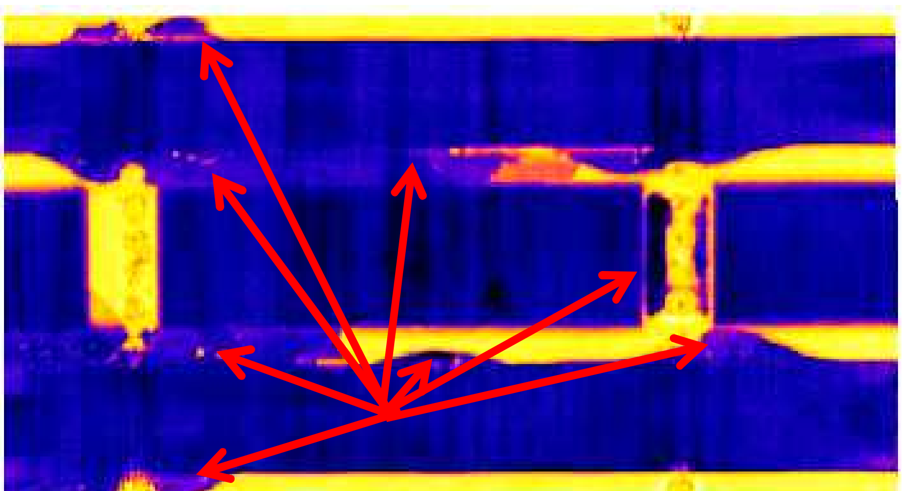
Stringer Fracture



Note: subsurface damage & comparison to visual inspection

Fracture of Co-Cured Joint at Stringer-Skin Interface



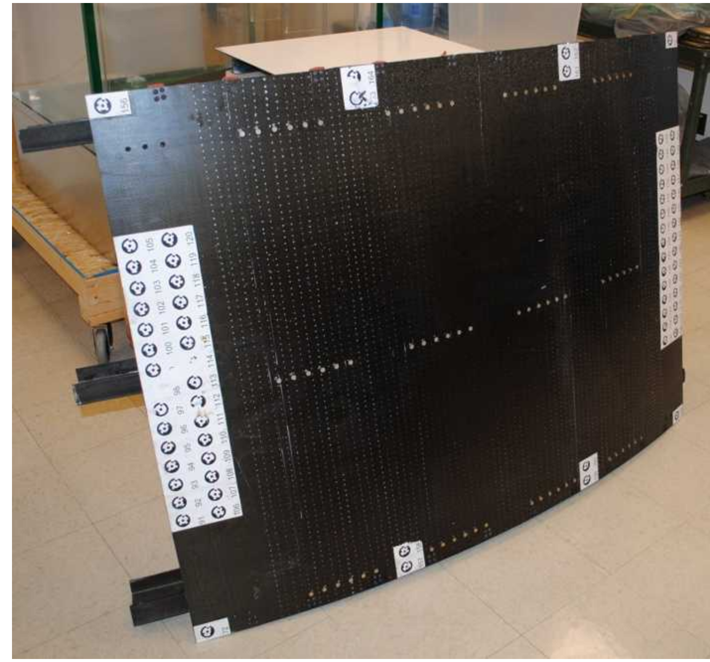


Stringer & shear tie areas that are not yellow correspond to disbonds.

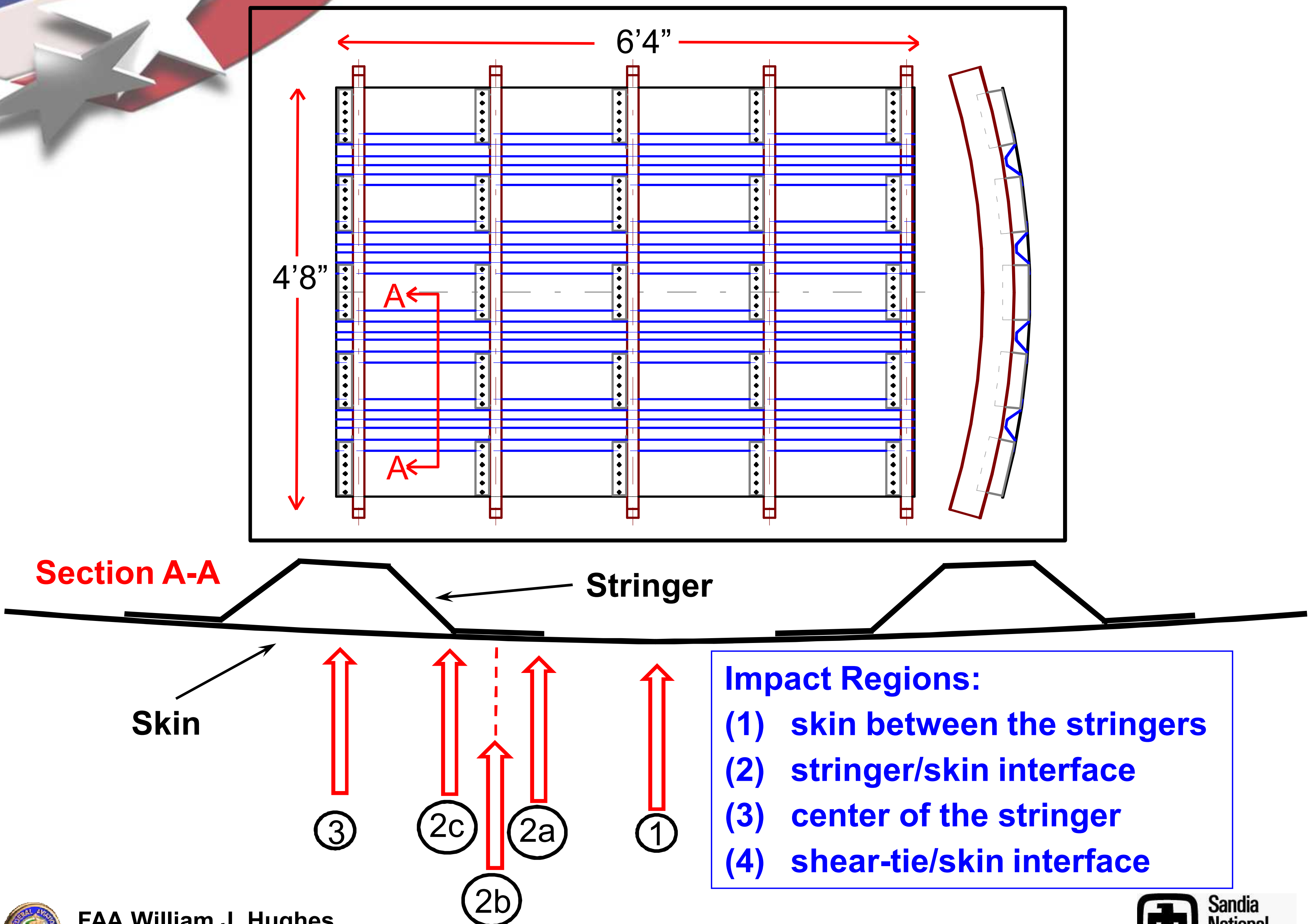
FAA William J. Hughes Technical Center

Sandia National Laboratories

Full-Scale Carbon Aircraft Panels for Impact Assessment



Full-scale carbon fiber aircraft fuselage section with co-cured stringers and attached frames



Impact Regions:

(1) skin between the stringers

(2) stringer/skin interface

(3) center of the stringer

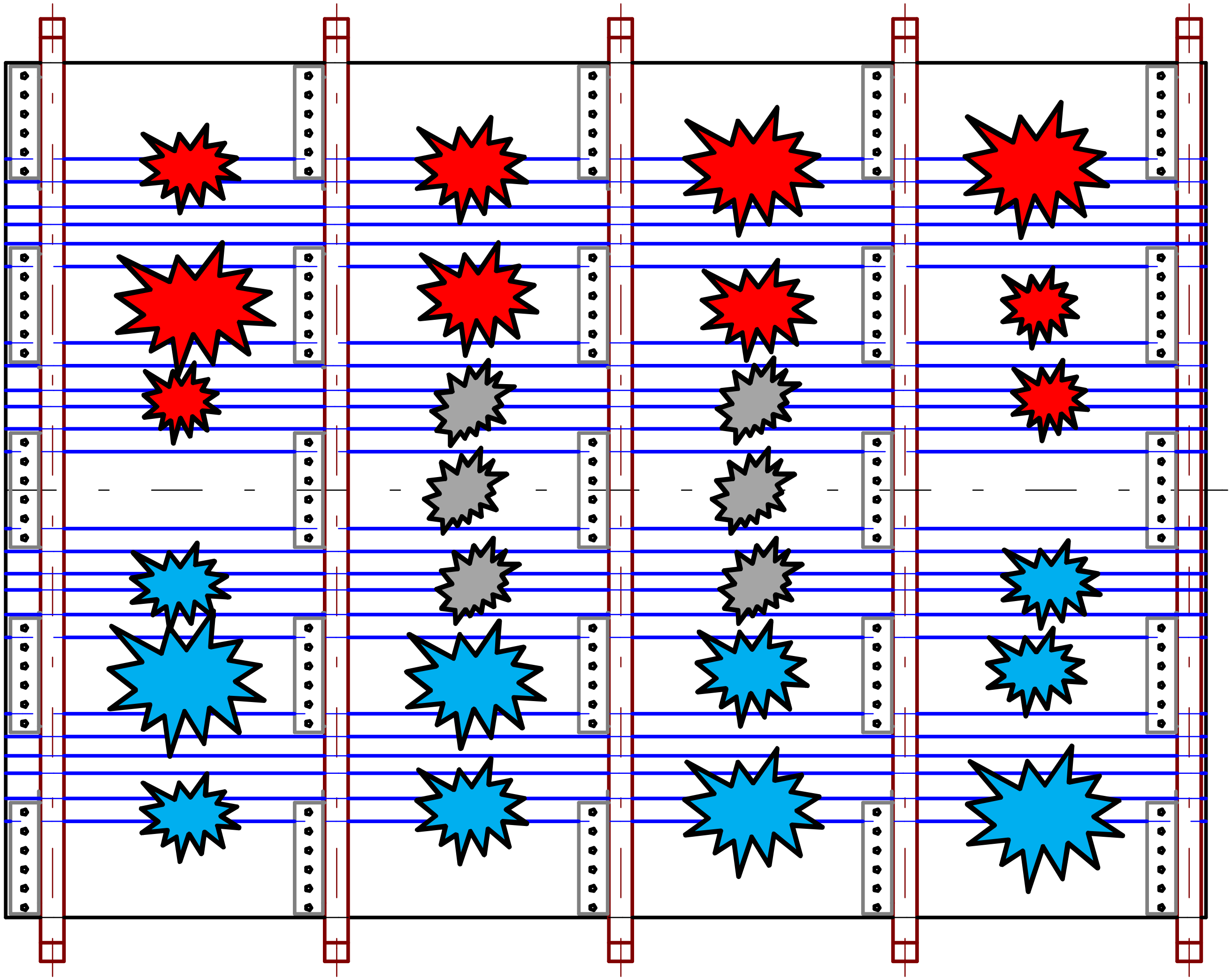
(4) shear-tie/skin interface

Schematic of Impact Damage

Drop Weight (hardened) Impact

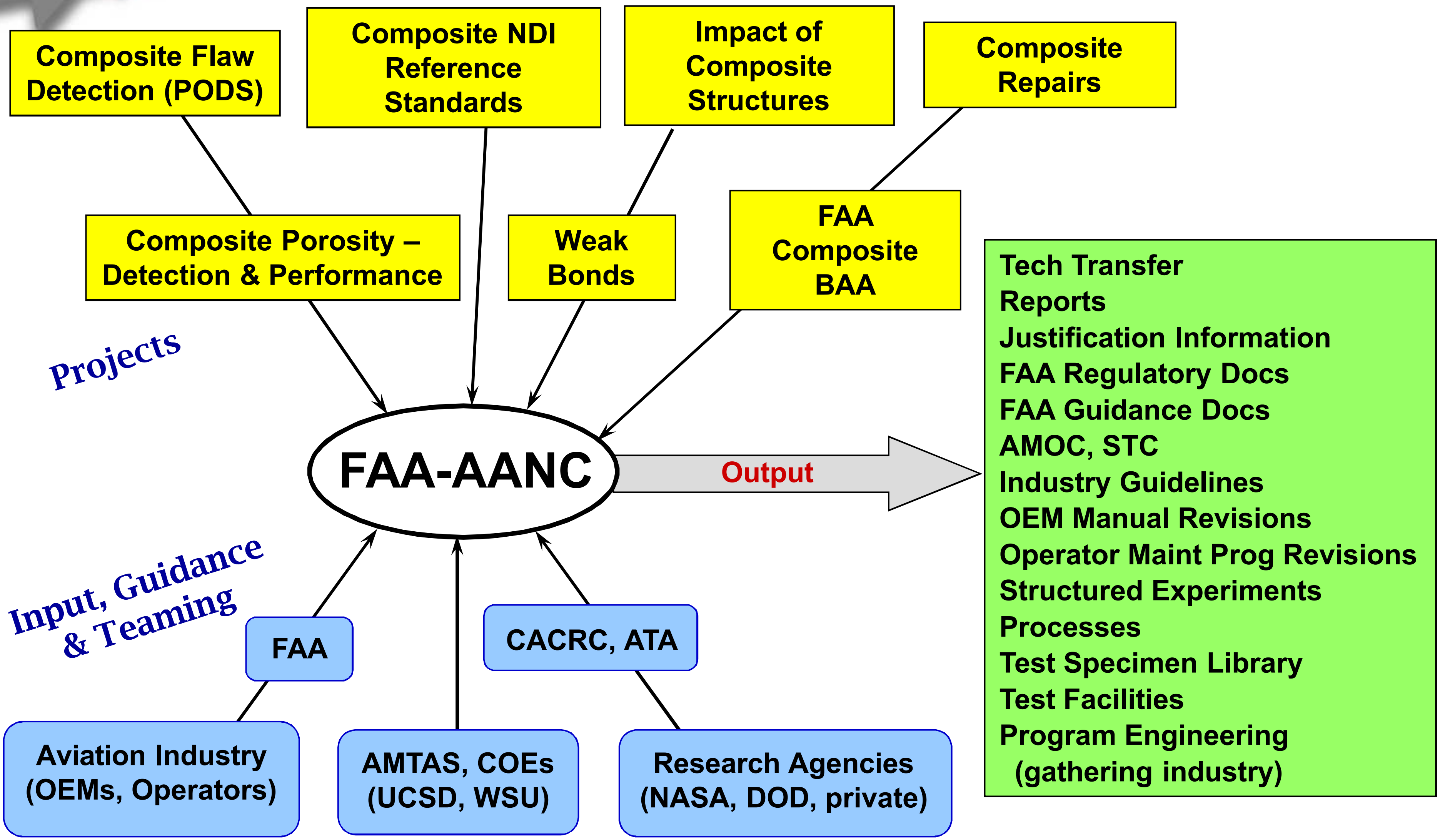
Quasi-Static Impact

Ice Impact



Damage location is divided into "bays" separated by stringers and frames (shear-ties) to avoid effect on neighboring impacts.

FAA-AANC Composite Programs



Conclusions – Inspection of Composite Structures

- Engineering and economic benefits of composites will continue to expand its use
- Impact damage is a primary concern (hidden subsurface damage)
- Composite Impact Study is:
  - Identifying impact scenarios of concern
  - Identifying key parameters governing impact damage
  - Characterizing FTE & overall impact threat
  - Relating damage threat to capabilities of NDI
- NDI ability to detect impact damage was assessed in FTE ~ BVID range → sensitivity, sizing, procedures, deployment
- 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

Inspection Options for Detecting Various Types of Impact Damage in Composite Structures

Dennis ROACH, Stephen NEIDIGK, Tom RICE, Randall DUVALL
FAA Airworthiness Assurance Center
Sandia National Laboratories,
Albuquerque, NM USA

Abstract

Aircraft structures made from polymer-matrix composites are vulnerable to damaged created by impact from ground vehicles/equipment, as well as from events such as hail and bird strikes. These impacts can create internal damage that is not visually detectable and thus of great concern from a damage tolerance and safety standpoint. The focus of this study is on the detection of damage stemming from a variety of impact types and the relationship between inspection capabilities and the damage resistance of carbon/epoxy tape laminates. Panels of varying thicknesses were impacted with a variety of impactors (hardened, hail, bumpers) where the input energy was derived from both high velocity-low mass and low velocity-high mass scenarios. Impact location was also varied in order to study the effect on substructure elements. Different nondestructive inspection (NDI) methods were applied to damage stemming from impacts in the vicinity of the failure threshold energies (FTE) of these composites. FTE is defined as the minimum amount of energy required to create initial delamination damage in the structure. Relationships between failure threshold velocity and the ratio of panel thickness to impactor diameter were determined and the sensitivities of multiple nondestructive inspection (NDI) methods were intercompared. NDI testing included both hand-held A-scan or meter response methods, as well as wide area C-scan mapping techniques. Rapid, "Go/No-Go" NDI devices were assessed to establish the viability of using gate-check inspections on in-service aircraft to identify damage of concern. The inspection portion of this impact study seeks to determine the ability of conventional and advanced NDI to detect hidden impact damage that is at or below the level referred to as Barely Visible Impact Damage (BVID). This study will allow flaw detection to be adequately judged based on the effects of impact on the structural integrity of composites. It will aid maintenance engineers in assessing whether an incident could have caused damage to a structure, and if so, what type of inspection technique should be applied to resolve the extent of damage.