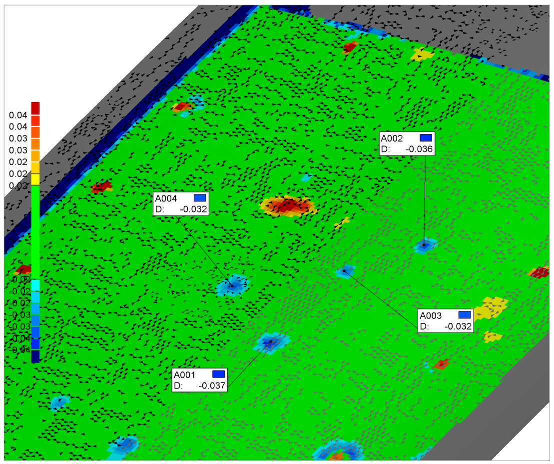
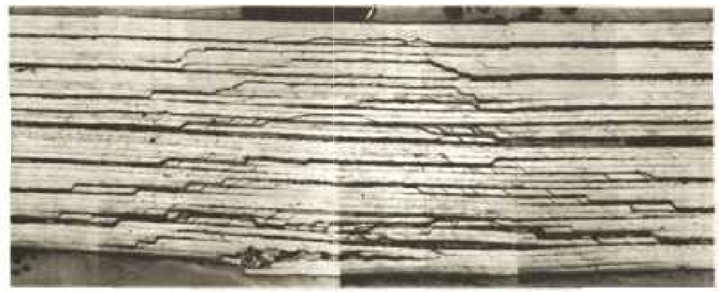
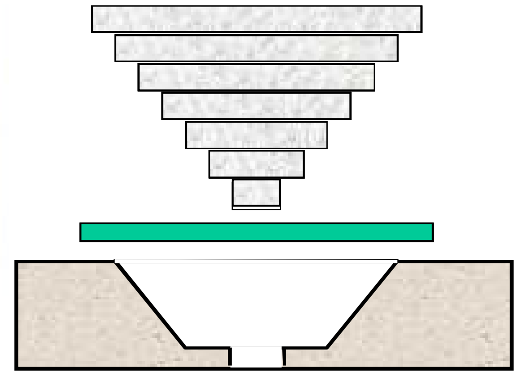
SAND2013-4305C

Improving In-Service Inspection of Composite Structures

CACRC Inspection Task Group Update

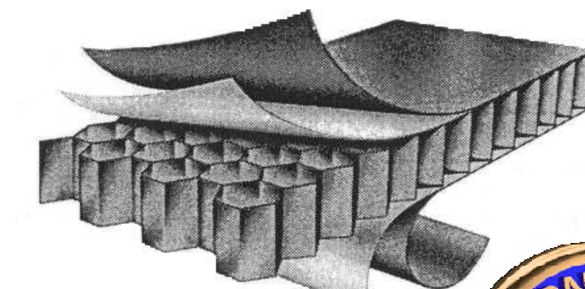






COMMERCIAL AIRCRAFT COMPOSITE REPAIR COMMITTEE

ata IATA SAE



Dennis Roach
Senior Scientist
Sandia National Labs
FAA Airworthiness Assurance Center

FEDERAL AVIATION ADMINISTRATION

SAND RAA5322872: rev 1

Inspection Task Group Team Participants

CACRC Inspection Task Group Members:

Wolfgang Bisle – Airbus *
Chris Dragan – Polish Air Force Institute of Technology
Don Duncan – US Airways *
Jim Hofer – Boeing *
Quincy Howard – Boeing *
Jeff Kollgaard – Boeing
Francois Landry – Bell Helicopter
Robert Luiten – KLM Airlines
Alex Melton – Delta Air Airlines *
Eric Mitchell – American Airlines *
Stephen Neidigk – Sandia Labs AANC *
Keith Phillips – Airbus
Tom Rice – Sandia Labs AANC *
Dennis Roach – Sandia Labs AANC (Chair) *
Vilmar da Silva do Vale – Embraer
Dennis von Seelen - Lufthansa Technik
Darrell Thornton – UPS *
Sam Tucker – United Airlines *
Roy Wong – Bombardier *

* Attended April 2013 ITG Meeting at FAA AANC Facility

*Rusty Jones, Larry Ilcewicz, Dave Galella *, Paul Swindell – FAA*

Inspection Task Group

ITG goal is to enhance aircraft safety by assessing & improving NDI flaw detection performance in composite aircraft structure

Deliverables:

- **Information on NDI performance & optimization for a comprehensive array of composite NDI requirements**
- **Authoring Aerospace Recommended Practice guidelines**
- **Information for FAA advisory material**
- **Assisting associated NDI integration efforts with OEMs & airlines**
- **Defining testing program for NDI evaluations**
- **Coordination of testing with airlines or NDI equipment developers**
- **Conducting test programs & reviewing test data with industry**
- **Relating results, as appropriate, to other CACRC task groups**

Composite Activities

- **Industry-wide Composite NDI Reference Standards**
  - Complete (SAE ARP5506 & 5507; DOE report completed)
- **NDI Assessment: Honeycomb Structures**
  - Experiments with conventional and advanced NDI completed
  - DOT report completed (conv. & adv. NDI)
- **NDI Assessment: Solid Laminate Structures**
  - Experiment development completed including protocols
  - Experiment completed at aircraft depots & with advanced NDI
  - Ramp Damage Check experiment
  - DOT reports completed (conv. NDI) and in-progress (adv. NDI)
- **Composite Impact Study**
  - Relate damage threat & structural integrity to capabilities of NDI to detect hidden impact damage in laminates
  - Hail, ground vehicle, hardened impact studies are underway

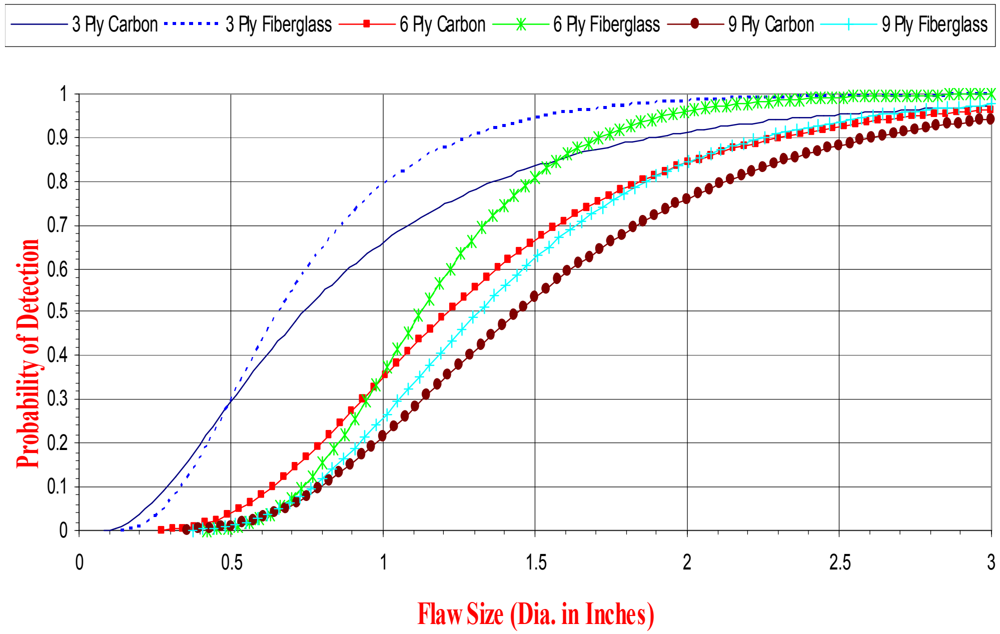
Assessing Composite Honeycomb Inspections

Composite Flaw Detection Experiment

Participation from over 25 airlines and maintenance depots

Industry-wide performance curves generated to quantify:

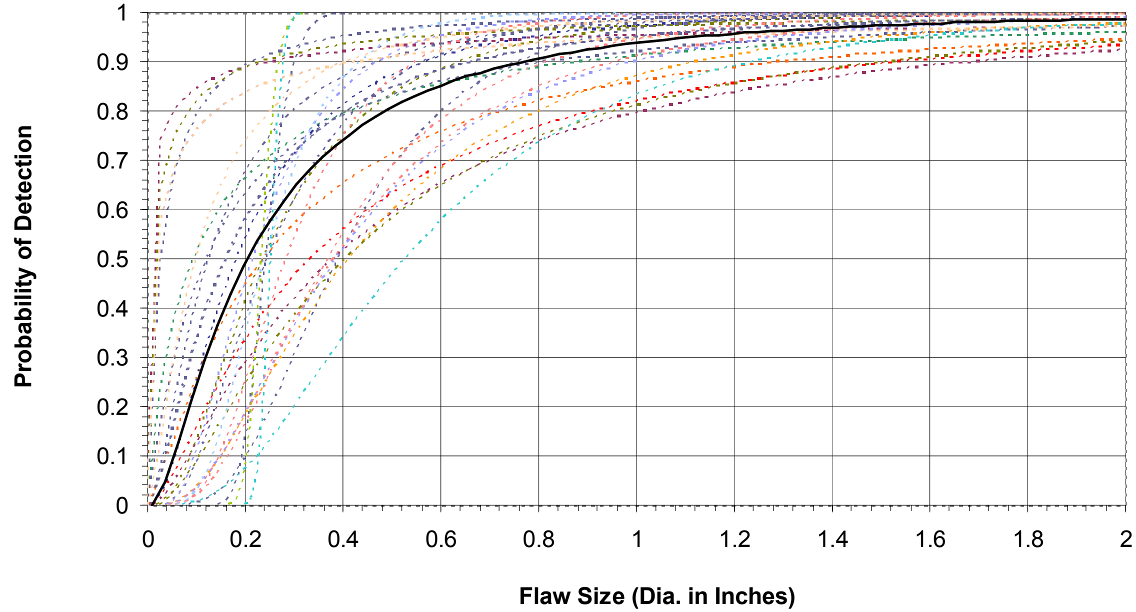
- **how well current inspection techniques are able to reliably find flaws in composite honeycomb structure**
- **the degree of improvements possible through integrating more advanced NDI techniques and procedures.**



Experiment to Assess Flaw Detection Performance

Solid Laminate Experiment Results

POD Curves for 20-32 Ply Solid Laminate Family

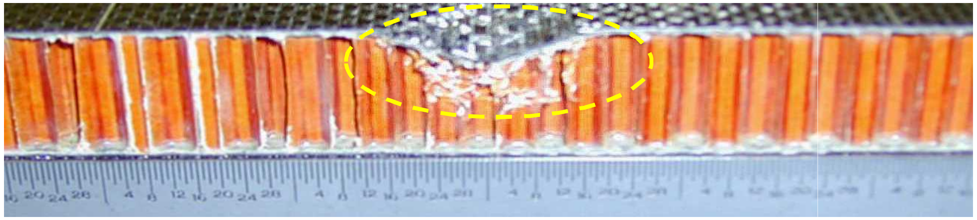


Individual and Cumulative Comparisons

False Calls: Constant thickness = 0.5/inspector
Complex Geometry = 0.0/inspector

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

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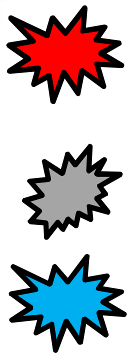
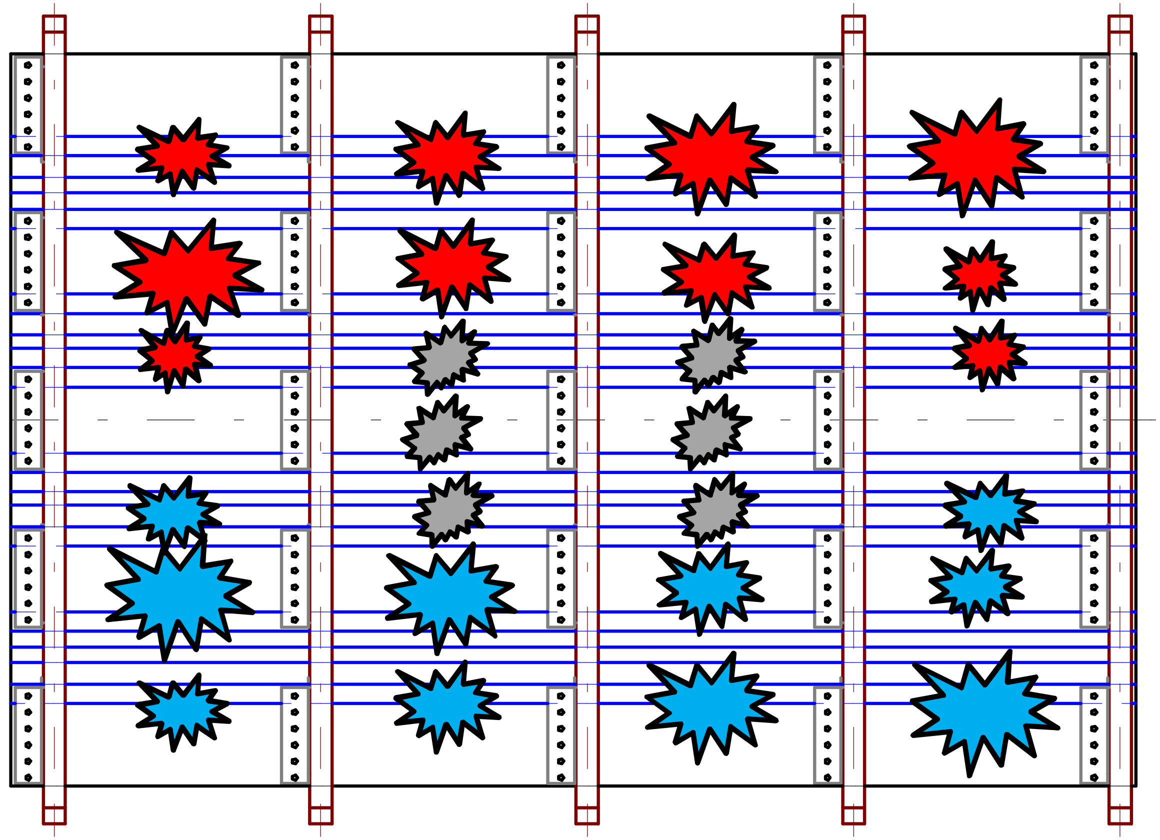
Impact Damage

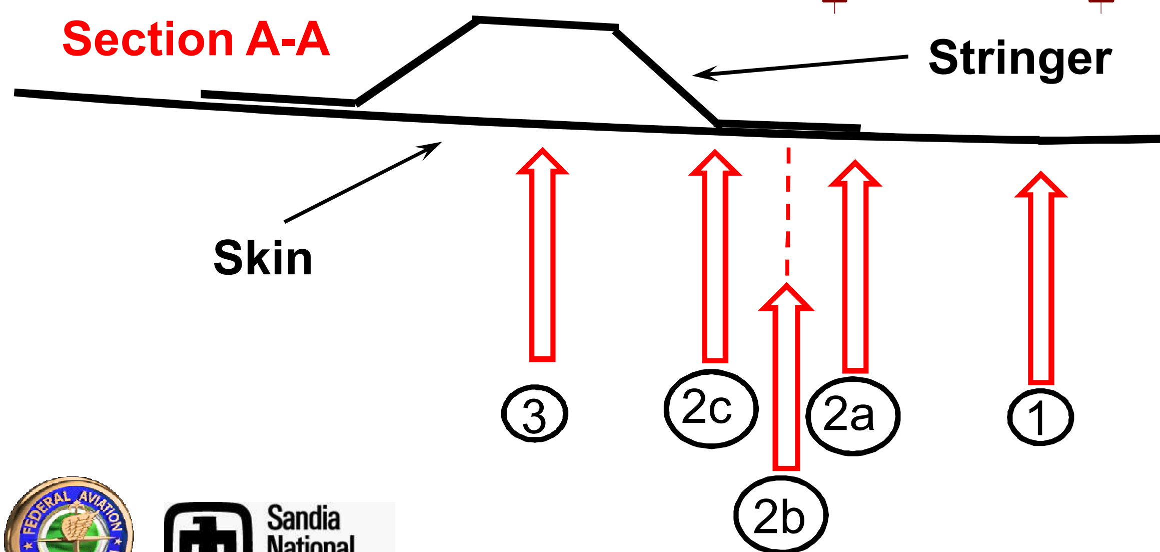


Drop Weight (hardened) Impact

Quasi-Static Impact

Ice Impact





Impact Regions:

(1) skin between the stringers

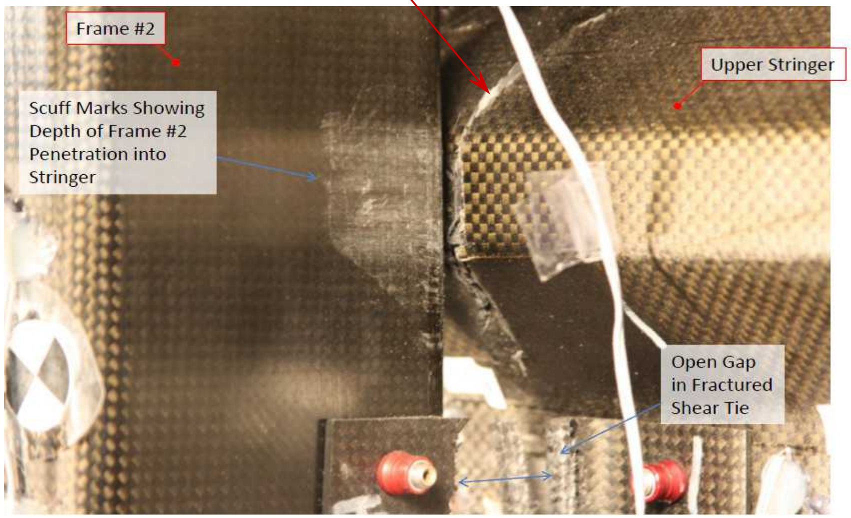
(2) stringer/skin interface

(3) center of the stringer

(4) shear-tie/skin interface

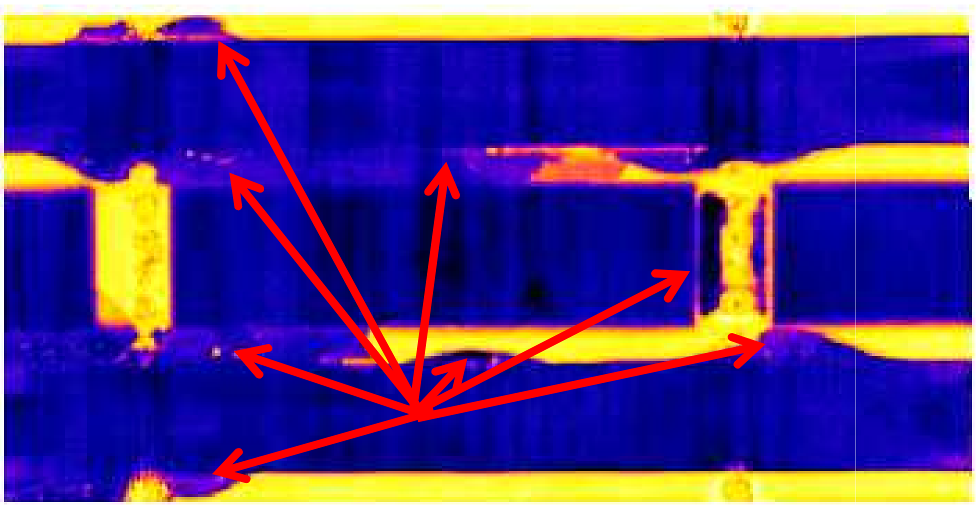
Inspection of Full Scale Panels with Low Velocity-High Mass Impacts

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.

Impact Damage Program Inspection Results from 24 Ply Panel

TC-24-11

Impact Energy (J) - 704 & 819

Flaw Size MAUS PE (mm²) - 8708

Flaw Size Omniscan PE (mm²) - 9030

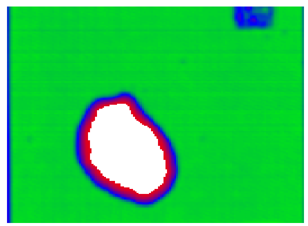
Flaw Size TTU UCSD (mm²) - n/a

Impact Velocity (m/s) - 151 & 163

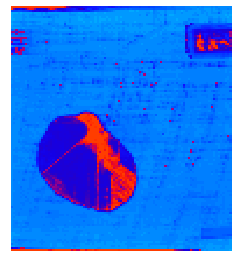
Projectile Size (mm) - 50.8

Picture

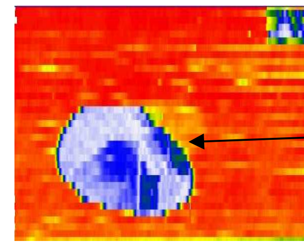
TTU



MAUS PE

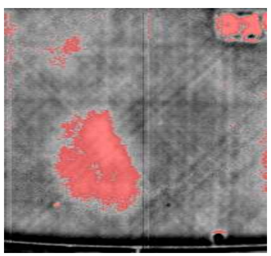


Omni PE

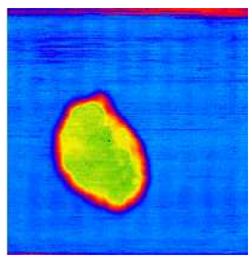


Large damage area

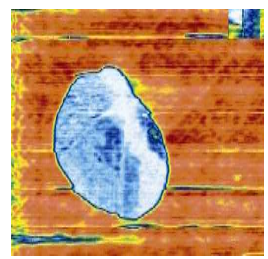
IR



MAUS Resonance



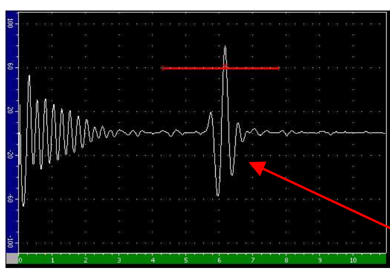
Omni PA



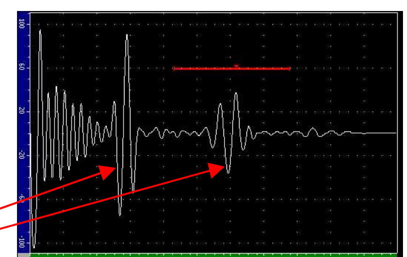
Bondcheck (flaw indicated)

Y

A-scan Ref



A-scan Flaw



Notice loss of backwall signal and new intermediate signal

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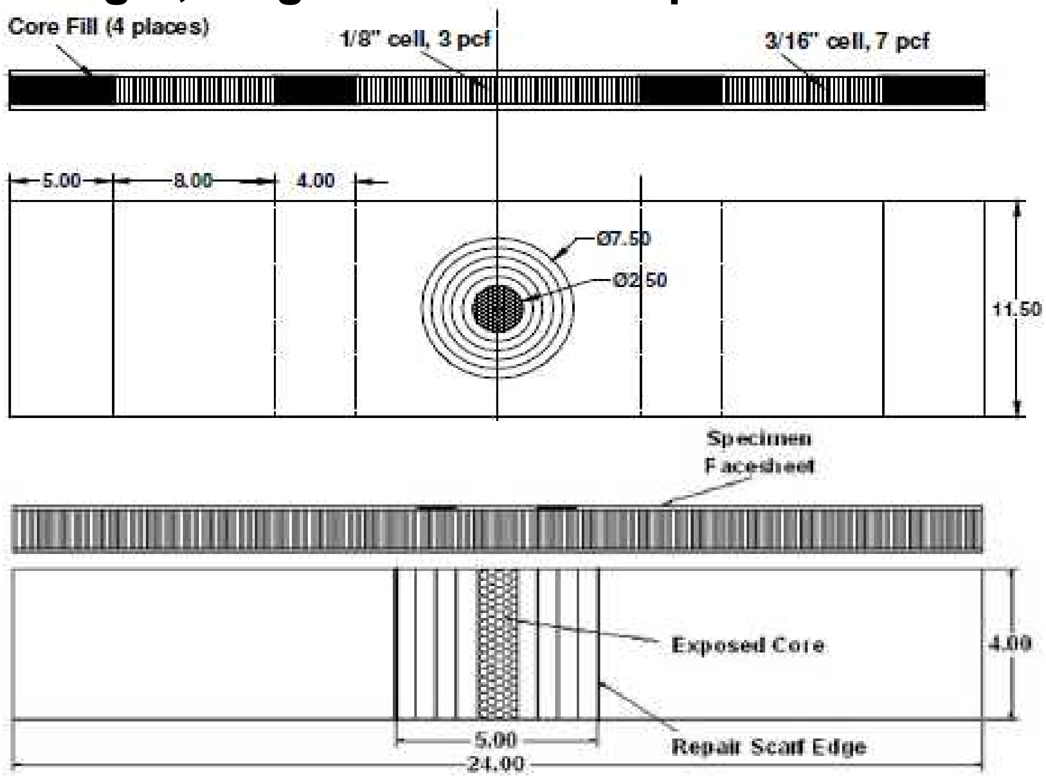
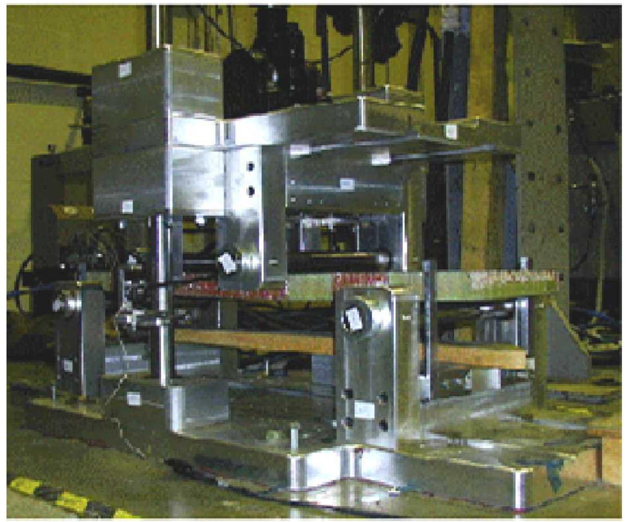
Composite Activities

- **Assessment of Heat Damage in Composite Laminates**
  - Optimize NDI sensitivity to thermal deterioration
  - Tie NDI results to structural assessments
- **Composite Repairs and Bonding**
  - Detection and quantification of weak bonds – co-cured, co-bonded & secondarily bonded configurations
  - Affect of porosity & nonuniform/high resin flow on NDI of repairs (honeycomb & solid laminate)
- **Composite Porosity**
  - NDI quantification of various porosity levels
  - Structural response – fatigue, residual strength, strain limits vs. NDI response (accept~reject thresholds)
- **Image-Based NDI for Composites**
  - Relate image-based, ramp-check inspections with depot-based NDI
- **Survey of Industry Composite NDI Training**

Composite NDI & Honeycomb Repair Systems – Compare Mechanical & NDI Performance

- Asses durability, repairability, maintainability
- Assess NDI for Allowable Damage Limit and bond integrity
- Round robin exercise comparing optimum with repair depot installations
- Study effects of contaminants, off-design repairs & flaws
- Wet lay-up and pre-preg repairs
- Strength, fatigue and NDI comparisons

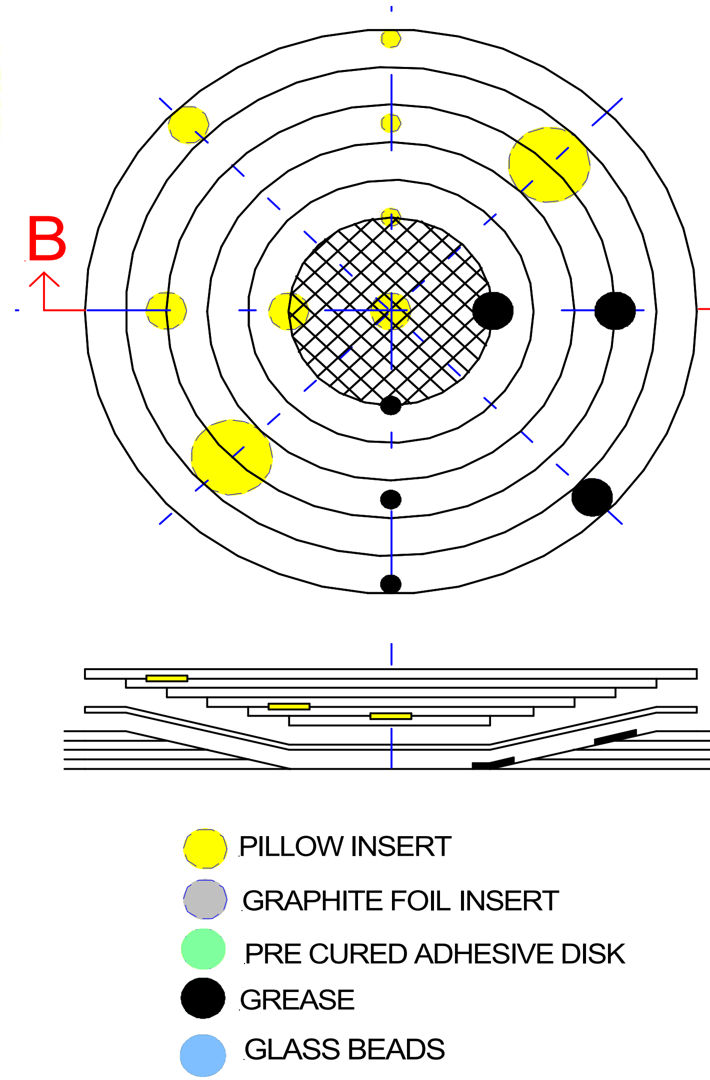




In collaboration with: WSU (L. Salah)

Composite Repair Test Matrix

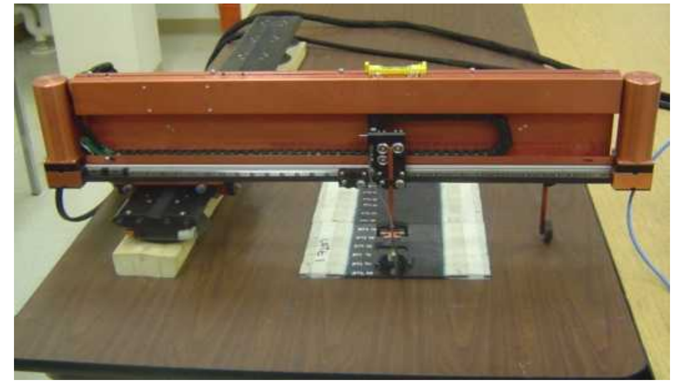
Variables	Repair	Loading Mode	Static			Fatigue	
			CTD	RTA	180W	RTF	180WF
Baseline Repair E parent = E repair	OEM-R1	Compression	3	3	3	3	3
	CACRC-R1	Compression	3	3	3	3	3
	CACRC-R2	Compression	3	3	3	3	3
Baseline Repair E parent = E repair	OEM-R1	Tension	3	3	3	3	3
	CACRC-R1	Tension	3	3	3	3	3
	CACRC-R2	Tension	3	3	3	3	3
Parent/ Repair Stiffness Mismatch	OEM-R1	Compression	3	3	3	3	3
	CACRC-R1	Compression	3	3	3	3	3
	CACRC-R2	Compression	3	3	3	3	3
Impact (BVID) Inclusions	OEM-R1	Compression		3	3	3	3
	CACRC-R1	Compression		3	3	3	3
	CACRC-R2	Compression			3		3
Contaminant 1: Pre-Bond Moisture - WA75	OEM-R1	Compression		3	3	3	3
	CACRC-R1	Compression		3	3	3	3
	CACRC-R2	Compression			3		3
Contaminant 2: Pre-Bond Moisture - Drying Cycles	OEM-R1	Compression		3	3	3	3
	CACRC-R1	Compression		3	3	3	3
	CACRC-R2	Compression			3		3
Contaminant 3: Skydrol + Water	OEM-R1	Compression		3	3	3	3
	CACRC-R1	Compression		3	3	3	3
	CACRC-R2	Compression			3		3
Cure Cycle Deviation 1	OEM-R1	Compression		3	3	3	3
	CACRC-R1	Compression		3	3	3	3
	CACRC-R2	Compression			3		3
Cure Cycle Deviation 2	OEM-R1	Compression		3	3	3	3
	CACRC-R1	Compression		3	3	3	3
	CACRC-R2	Compression			3		3



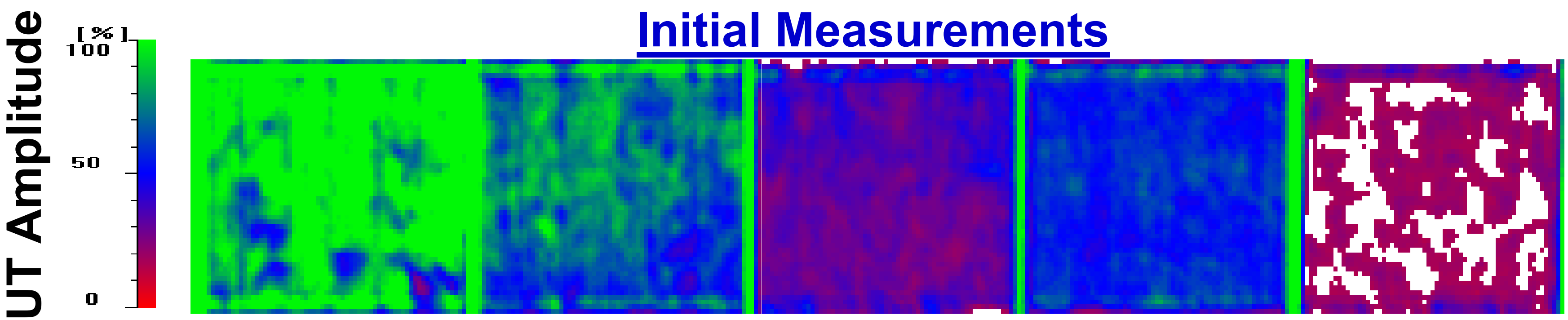
Composite Porosity Program – Pulse Echo UT Results

<u>Structural Integrity vs. NDI Testing Process</u>

1. Determine baselines – ultimate strength, E, and NDI response
2. Tension-Tension fatigue tests at 75-85% of respective ultimate strength; up to 120K cycles (two lifetimes)
3. Periodically take mechanical and UT property measurements at different fatigue levels
4. Determine residual strength of unfailed specimens



Initial Measurements



Sample Set (Porosity) Initial Modulus Ultimate Failure	BT2 43-58	CT2 43-48	IIA 12-17	IIIA 12-17	IV 12-17
(Porosity)	(0.3 – 0.6 %)	(2 – 3 %)	(7 – 8 %)	(7.5 – 8.5%)	(9.3 – 9.7%)
Initial Modulus	69 GPa	67 GPa	69 GPa	68 GPa	68 GPa
Ultimate Failure	71 kN	69 kN	69.5 kN	66.6 kN	69.7 kN

Increased porosity does not make a significant difference in the initial ultimate strength or modulus of elasticity

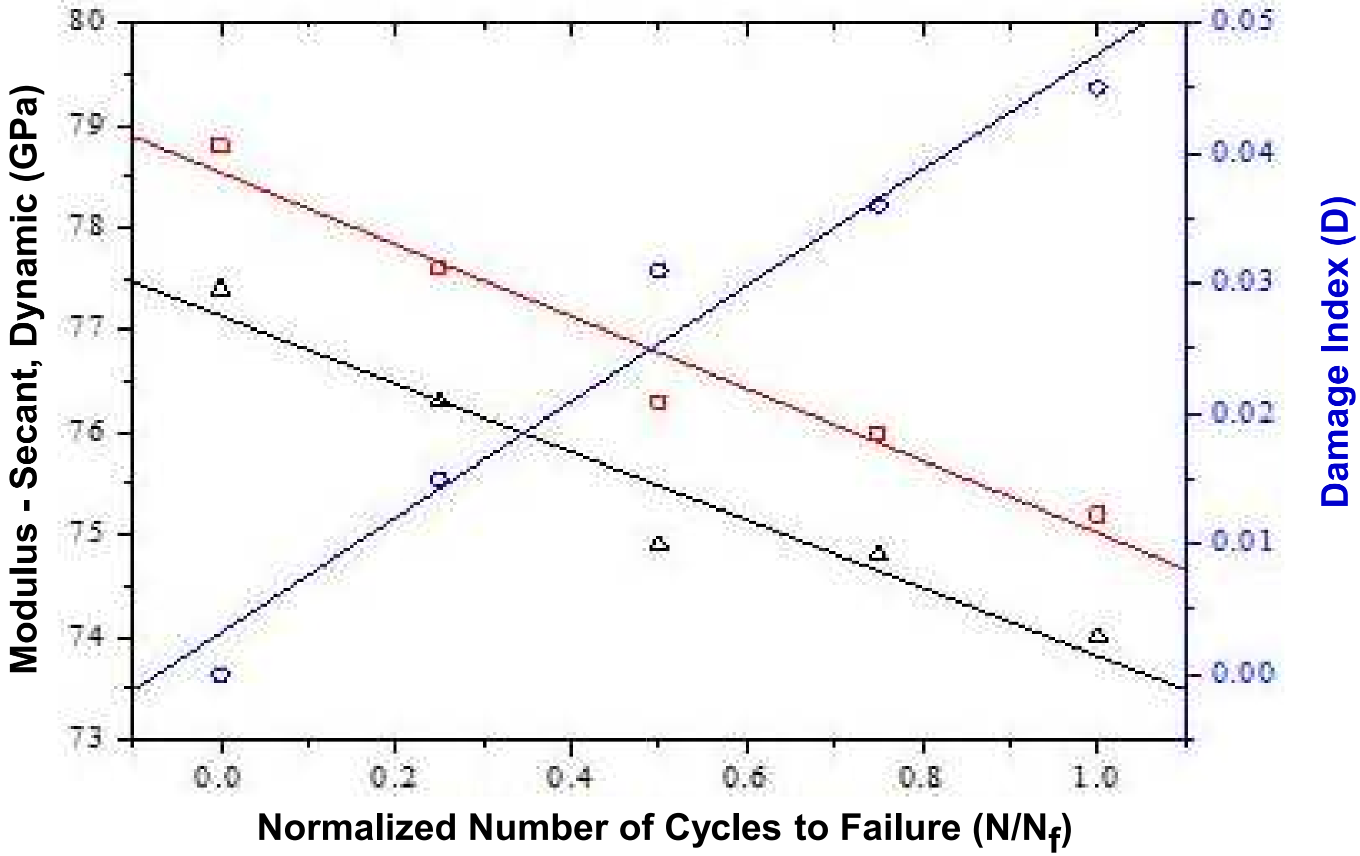
Relating Composite Porosity with Accumulated Damage, Modulus and NDI

Damage Index is related to stiffness degradation

$D(n) = 1 - E(n)/E(o)$

$E(o)$ = E initial

$E(n)$ = E at fatigue cycle n

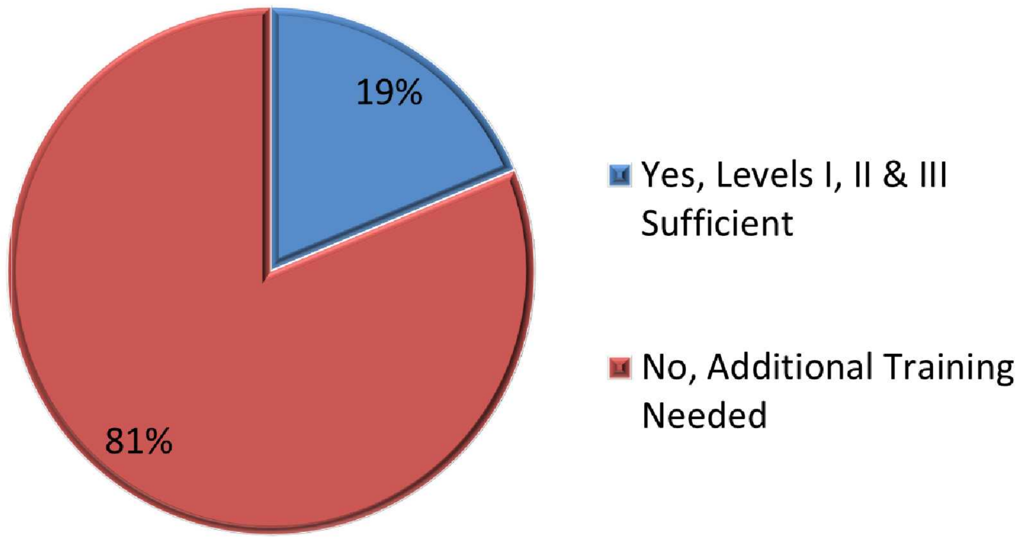


Δ Secant Modulus ◻ Dynamic Modulus O Damage

Survey of Industry Composite NDI Training

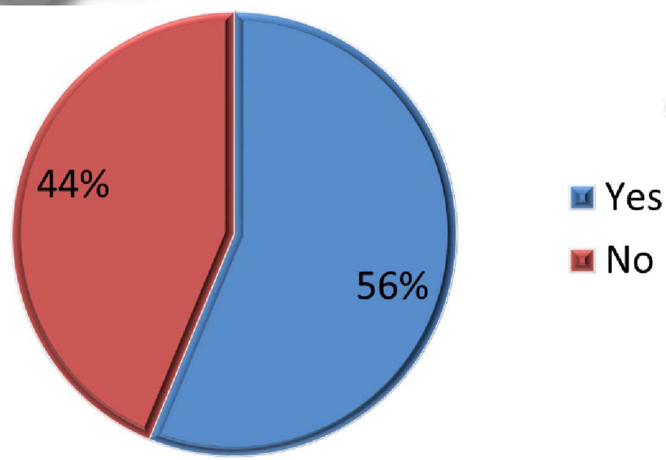
Question 16 - In your opinion, do Level I, II, and III training/qualifications provide the necessary expertise for both metal and composite NDI or should additional training take place for composite inspections?

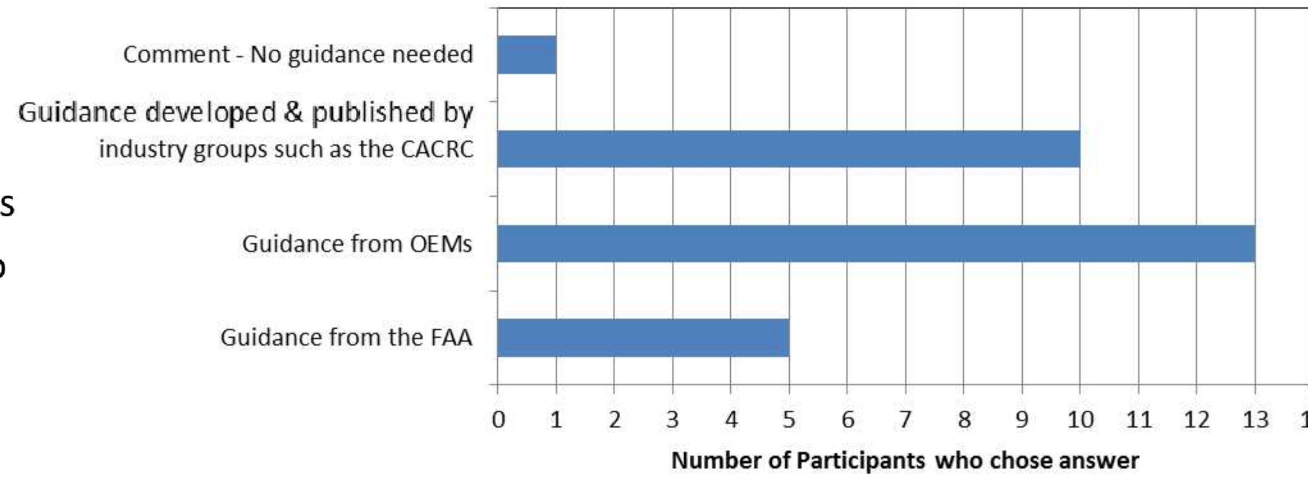
Composite NDI Training Survey Status - 05/07/13		
	Company	Completed
1	AAR-ASI (Indy)	Yes
2	American Airlines (Tulsa)	Yes
3	Aviation Technical Services, Inc (Seattle)	Yes
4	Delta Air Lines (Atlanta)	Yes
5	Delta/Northwest Air Lines (MN)	Yes
6	FedEx (Indy)	Yes
7	FedEx (Las Angeles)	Yes
8	Goodrich Aerostructures (UTAS) (Chula Vista)	Yes
9	Kalitta Air LLC (Michigan)	Yes
10	Rohr Aero Services LLC (Goodrich, UTAS Alabama)	Yes
11	Southwest Airlines (TX)	Yes
12	Timco (Georgia)	Yes
13	United Airlines (San Fran.)	Yes
14	United/Continental Airlines (Houston)	Yes
15	UPS (KY)	Yes
16	US Airways (PA)	Yes
17	Aeroframe Services, LLC (Louisiana)	No
18	Alaska Airlines	No
19	Nordam (OK)	No
20	ST Aerospace (AL)	No



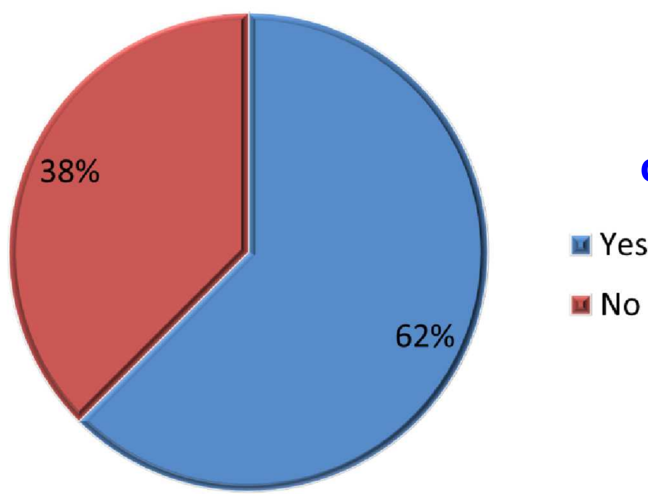
Only 25% of responders currently have special composite NDI training in place

Question 21 - In what areas is additional guidance needed to help ensure comprehensive composite training programs for the aviation industry?





Question 15 - If experience level is a factor in determining qualification to perform certain inspections, do you use some sort of apprentice program to expose newer inspectors to such inspections?



Question 5 – Do inspectors also receive general composite training to understand composite materials, plies, lay-ups, scarfed repairs, composite design, composite processing, etc.?

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Inspection Task Group

Major Accomplishments at April ITG Meeting:

- **Review of Ongoing ITG Activities – purpose, approach, results; solicit team input on continued work while identifying roles of team members**
- **Discussion on Composite NDI Needs – identify current & future perceived needs for improved NDI methods, procedures, ref. stds., training**
- **Discussion on Airline Composite Experiences – NDI field experiences & lessons learned**
- **Identification of Possible New ITG Activities - expected output for industry adoption**

Inspection Task Group

<u>***Proposed New ITG Work:***</u>

- **Custom NDI Reference Standards for Composite NDI** – accommodate porosity measurements, phased array UT, coating standards, added realism
- **Composite NDI Training and Training Aids** – realistic NDI specimens, increase exposure to composite inspections with feedback & supplemental training
- **Enhanced/Custom NDI Validation** - fluid ingress vs. delaminations; effect of coatings (e.g. LSP) on NDI
- **Quantify NDI Performance** – custom application of Composite Laminate Flaw Detection Experiment; continued evaluation of airlines after additional training/exposure; PA-UT; assess viability of NDI Remote Expert System (two-man team)

Inspection Task Group

Document Status - Expected Output of ITG Tasks for Adoption by Industry:

- **Update "Composite Repair NDT/NDI Handbook" (ARP 5089)** - include results & best practices from composite honeycomb and composite laminate flaw detection studies; complete needed corrections; improve emphasis on solid composite laminate NDI; include enhanced/custom NDI validation results
- **FAA Advisory Material** - Placement of appropriate information into FAA ACs was noted as a good way to facilitate adoption of best NDI practices at aircraft maintenance facilities (TBD)
- **Additional NDI Ref Stds** - expansion update to "Solid Composite Laminate NDI Reference Standards" (ARP5605) and "Composite Honeycomb NDI Reference Standards" (5606); option: reference in OEM NDT Standard Practice Manuals and Nondestructive Testing Manuals
- **Composite NDI Training and Training Aids** – Produce a new composite NDI training ARP and determine an appropriate way for it to be referenced by ATA-105, NAS410/ASNT, EN4179 (coordinate activity with these groups)
- **Quantify NDI Performance** – establish database on NDI performance, determine limitations & personnel qualifications; dissemination & industry adoption TBD

FAA proposal (AANC) and authorization from CACRC EC

CACRC Inspection Task Group Update and Overview

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