FAA R&D in Composite Sandwich Structures

Federal Aviation Administration

Presented to: Damage Tolerance & Maintenance Workshop

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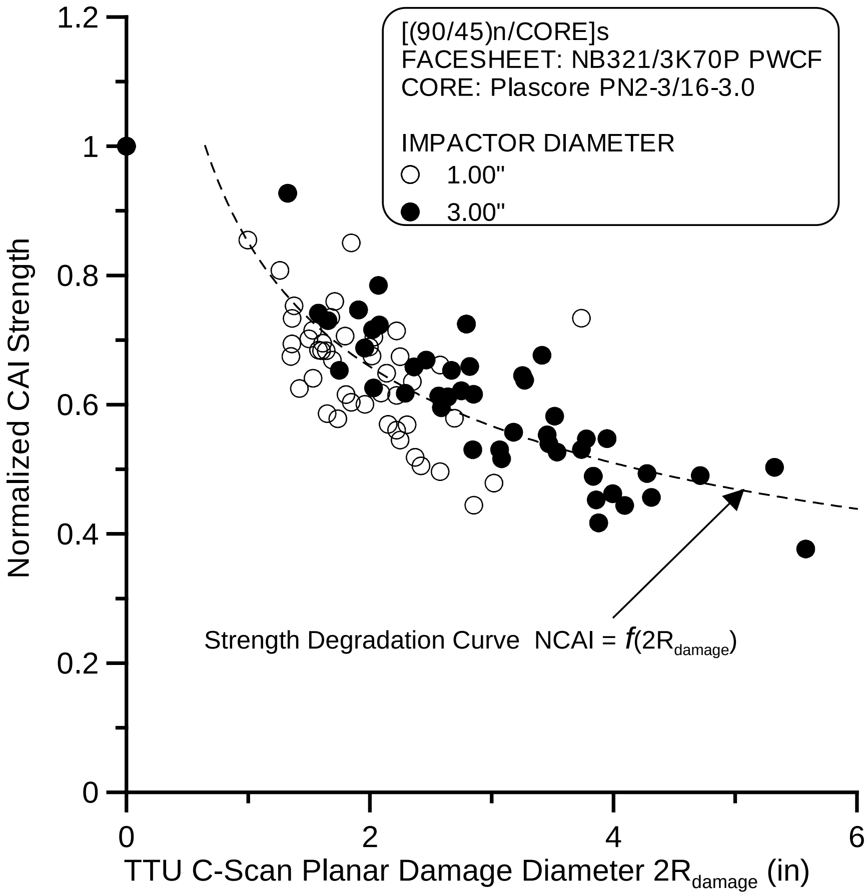
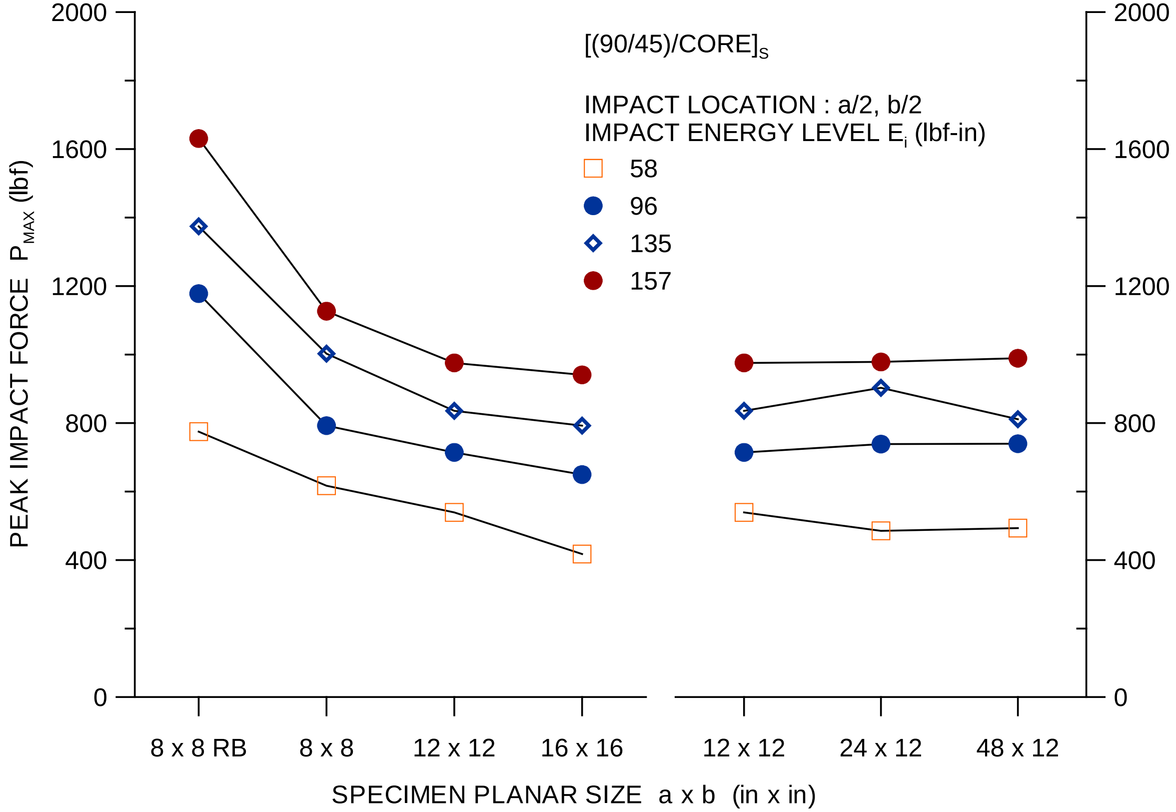
Content

- **Impact Damage Effects on Compressive Residual Strength**
  - Scaling effects
  - Comparison with tensile and compressive open hole tests
- **Repair Considerations**
  - Lap length and impact effects
  - Processing effects
  - Effectiveness of NDI

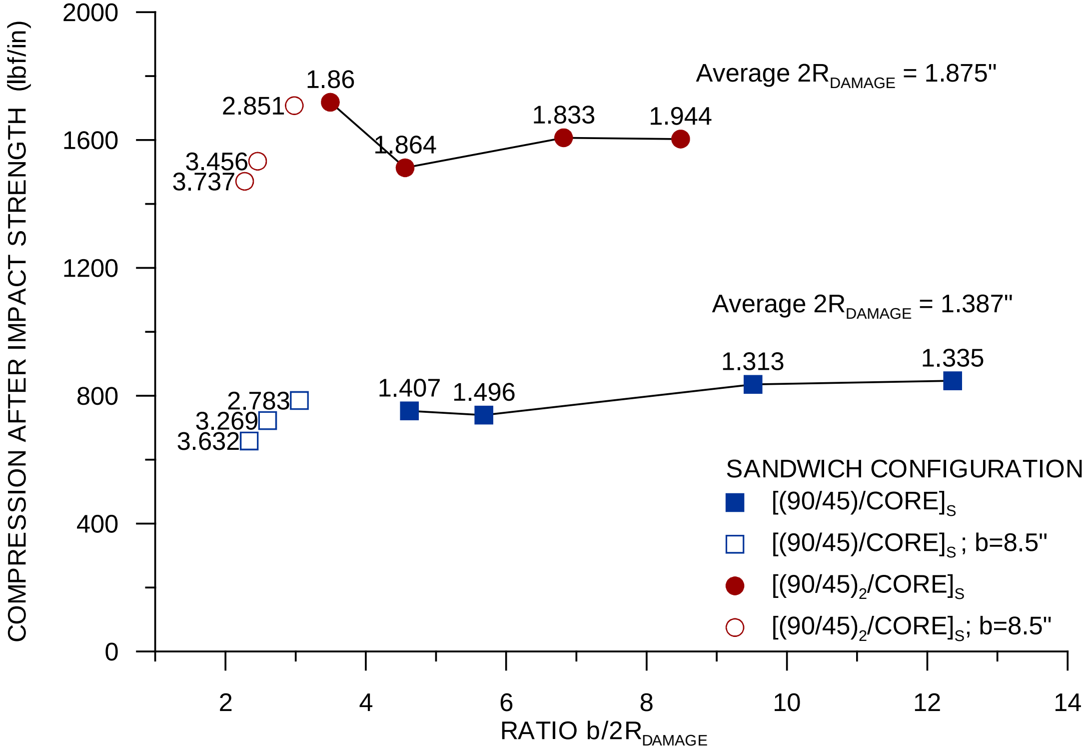
Compressive residual strength after impact



Peak impact force for different panels and impact energy



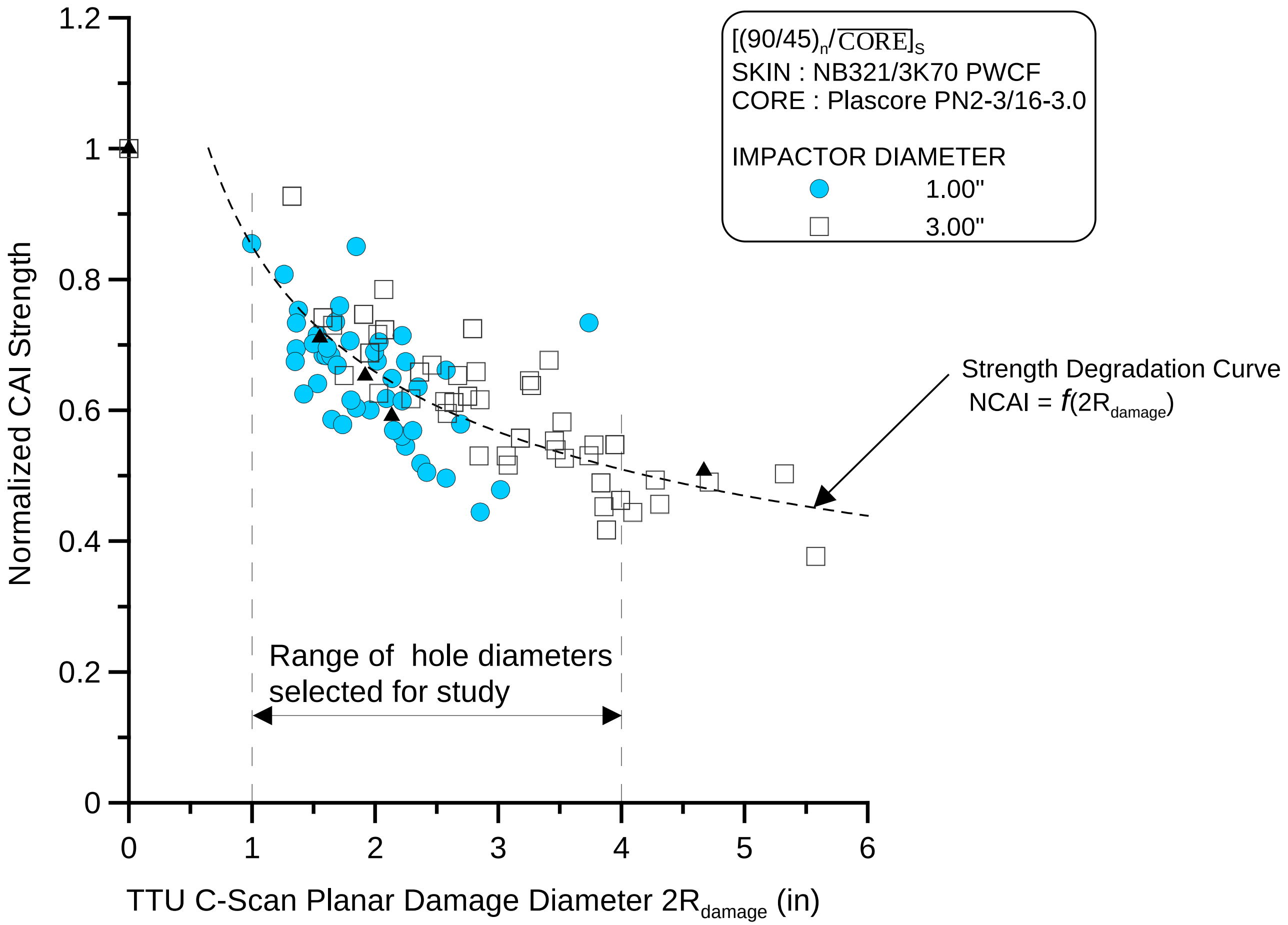
Effect of increasing width on compressive residual strength



Scaling study conclusions

- Damage resistance is reduced if one planar dimension is reduced; governed by global stiffness
- Damage tolerance does not seem to be affected by increasing the width if the damage state remains the same. Smaller specimen give slightly conservative but valid results if the damage size and failure mechanisms are monitored to ensure that the finite width effects are correctly accounted for.

Impact data and open hole dimensions



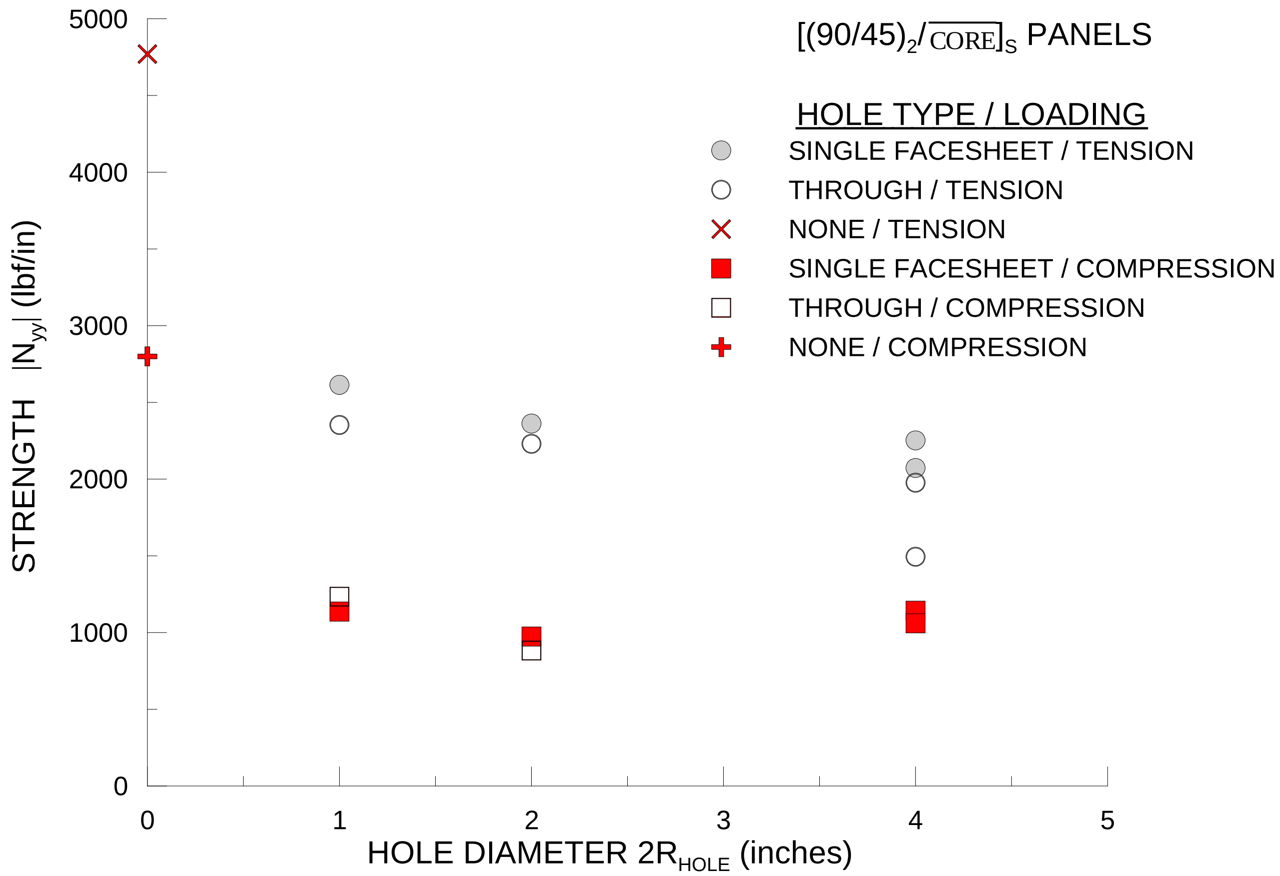
Open-hole compression test variables

- Two, four, and six ply face-sheets
- 1, 2, 4 in. diameter holes
- Single face-sheet and through holes
- Panels with width of 8.5 in. and 10.5 in. and 30 in. height and 17 in. width and 30 in. height
- W/D ratios of 2.125, 4.25. and 8.5
- Total of 16 panels

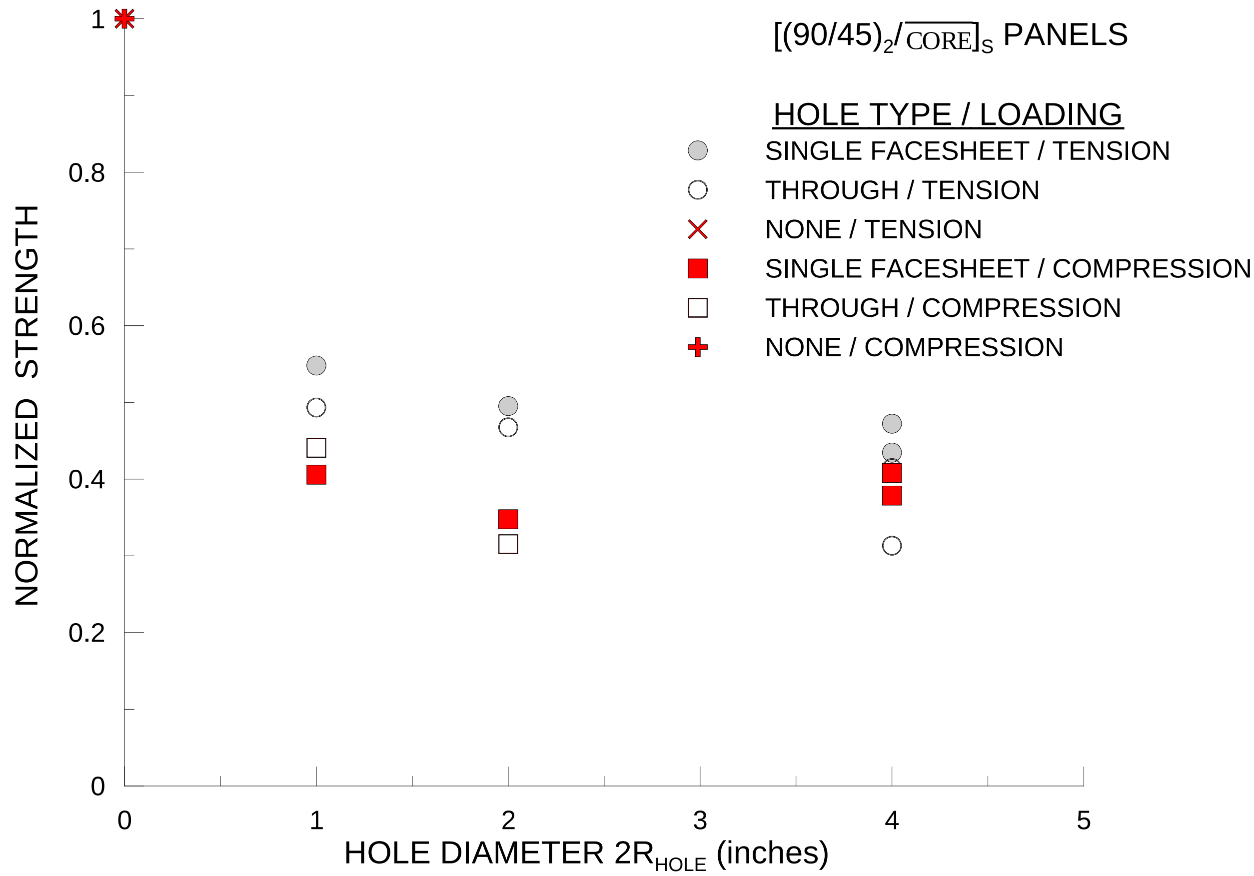
Open-hole tension test variables

- Two ply face-sheets
- 1, 2, 4 in. diameter holes
- Single face-sheet and through holes
- Panels with width of 8.5 in. and 10 in., 20 in., and 40 in. length and 17 in. width and 40 in. length
- W/D ratios of 2.125, 4.25. and 8.5
- Total of 8 panels

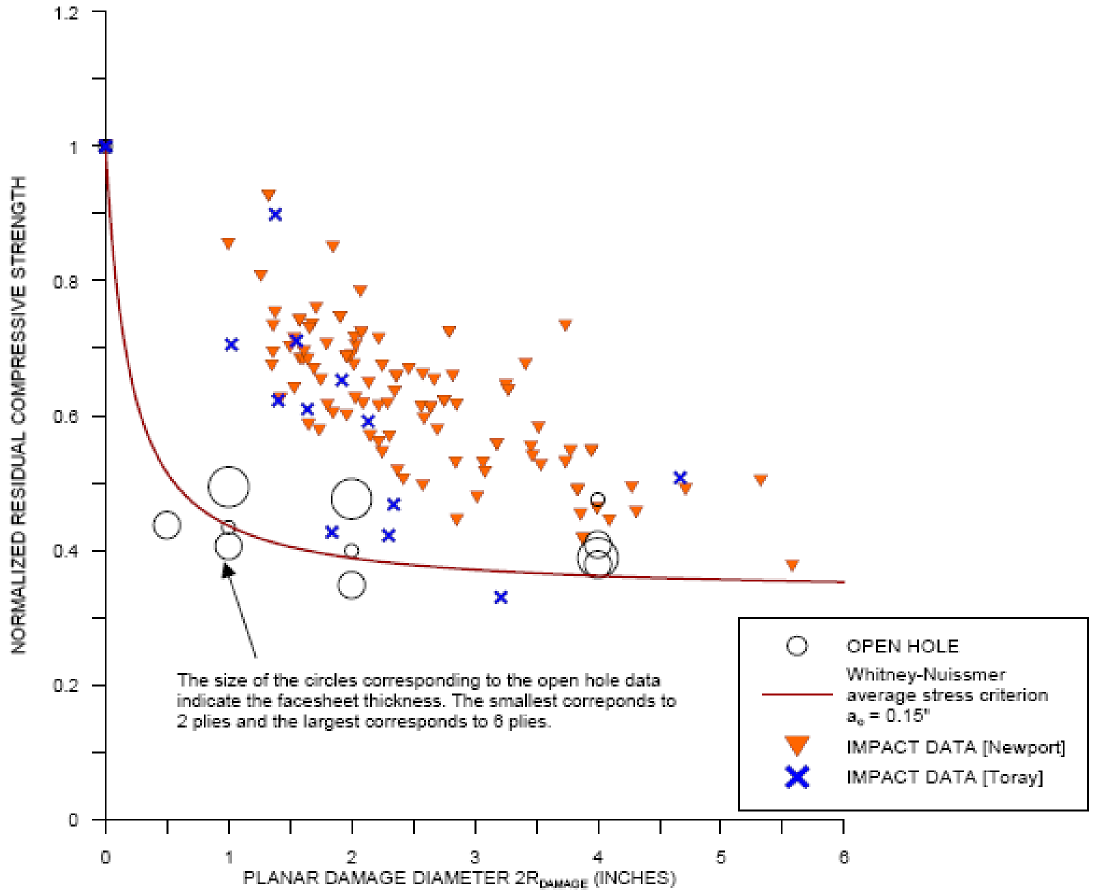
Open-hole strengths



Open-hole strengths- normalized



Open-hole and impacted compression strengths- combined data



Open-hole testing conclusions

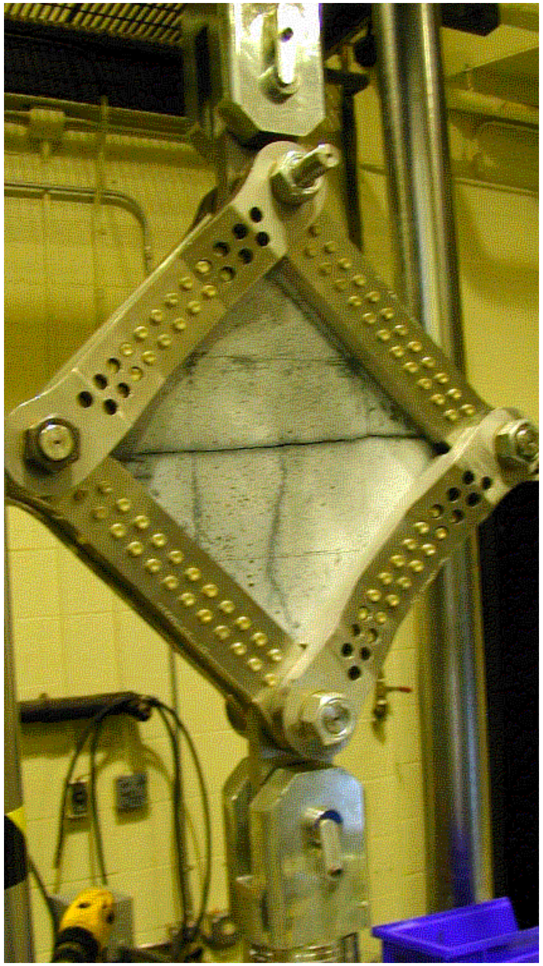
- Open hole more critical than impact damage for equivalent damage size
- Through hole more severe than hole to one face-sheet
- Compression more critical than tension
- Increase in indentation depth approach open hole results
- In compression, face-sheet fracture failure mode was observed for small diameter holes in one face-sheet and for through holes of all sizes
- For 4 in. diameter holes in one face-sheet local instability mode was observed that blunted the stress concentration resulting in higher compressive strengths

Future work – damage tolerance

- Large-scale tests on fuselage panels under pressure and tension longitudinal loads
  - Large damage
  - Repairs
- Scope to be presented by John Tomblin on full-scale testing

CACRC investigation

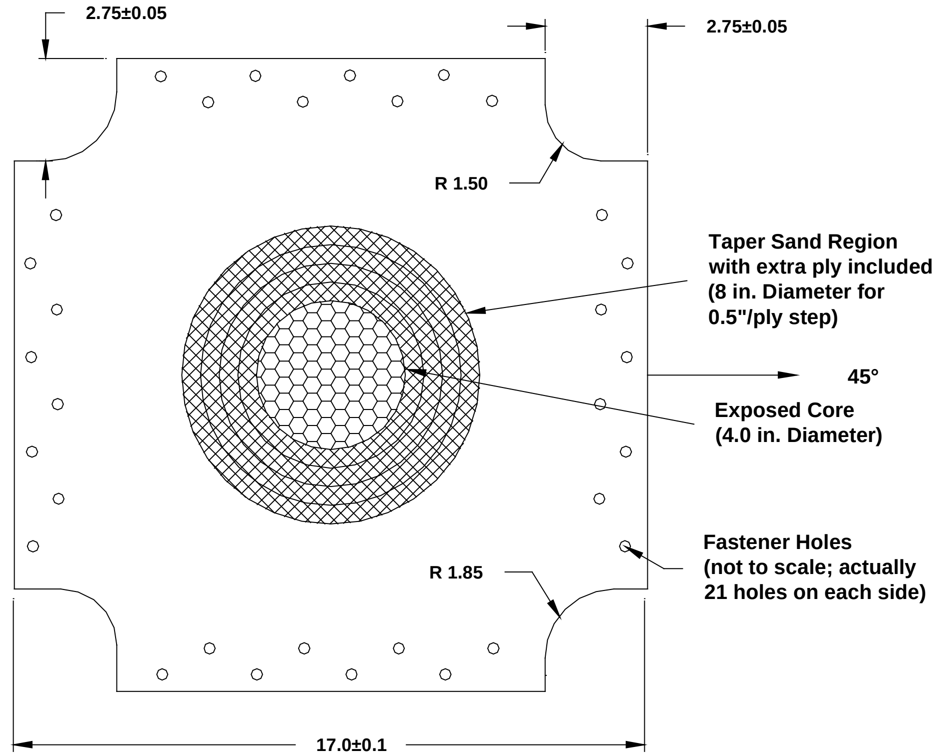
- Picture frame shear coupons manufactured by the OEM
- Three-ply graphite epoxy face-sheets, 3/8” core
- The coupons were impacted and inspected
- 30, of the 57 coupons supplied by the OEM, were sent to 5 different airline depots, six coupons to each depot. The coupons were to be inspected and subsequently repaired
- 2 repair methods, an OEM prepreg 350°F cure method and a CACRC wet lay-up repair method 250°F cure
- The main goal was to investigate the repeatability of these repairs when performed by different operators

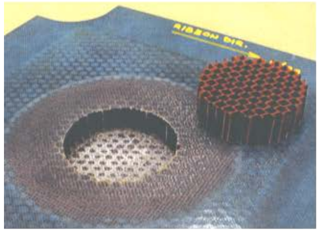


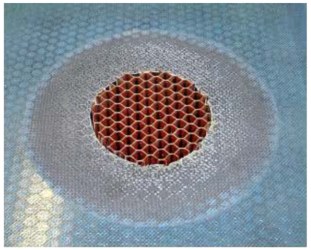
CACRC investigation

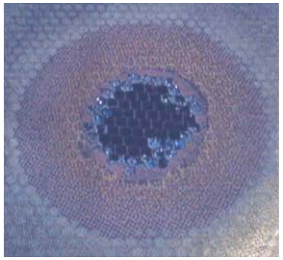
CACRC WET LAY-UP REPAIR PROCEDURE

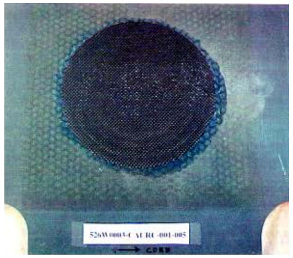
- Repair material: Epocast 52 A/B laminating resin with TENEX Fibers
- 0.5” overlap
- 1 extra ply
- 200°F cure







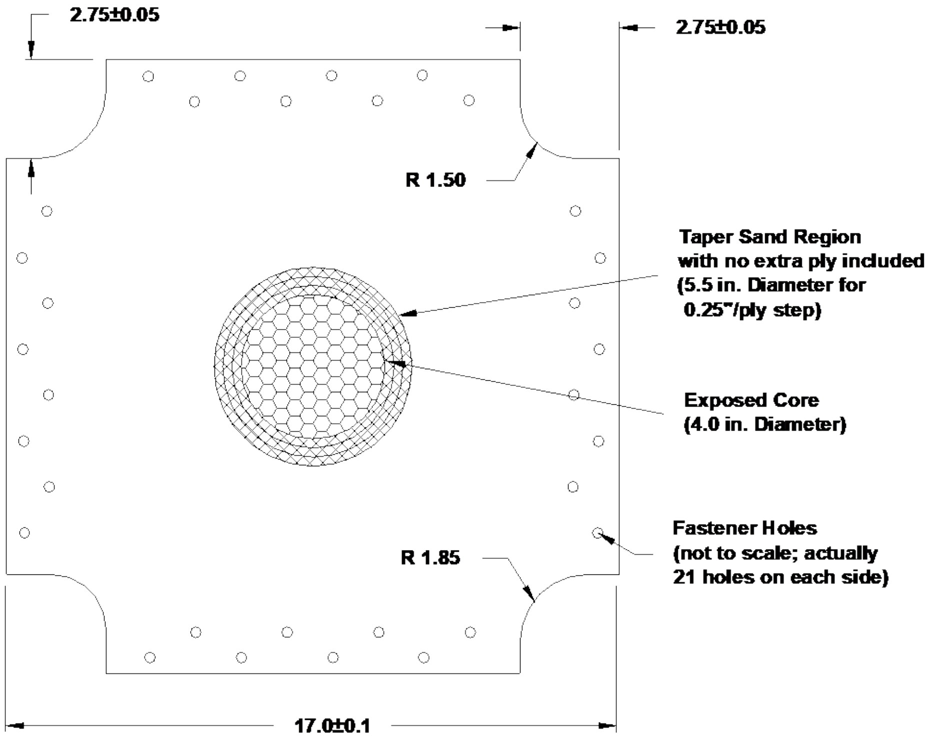


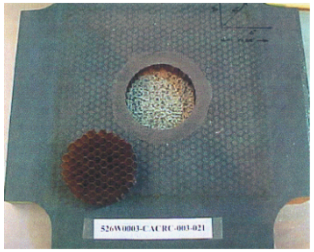


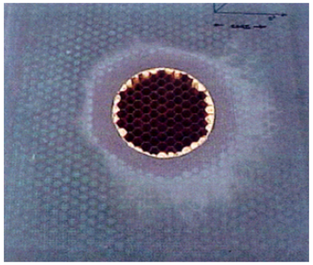
CACRC investigation

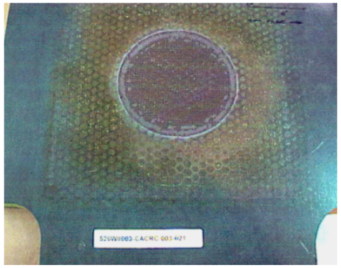
OEM PREPREG REPAIR PROCEDURE

- **Repair material:**
  T300/934 3K-70-PW prepreg with FM 377S adhesive
- **0.25” overlap**
- **No extra ply**
- **350°F cure**









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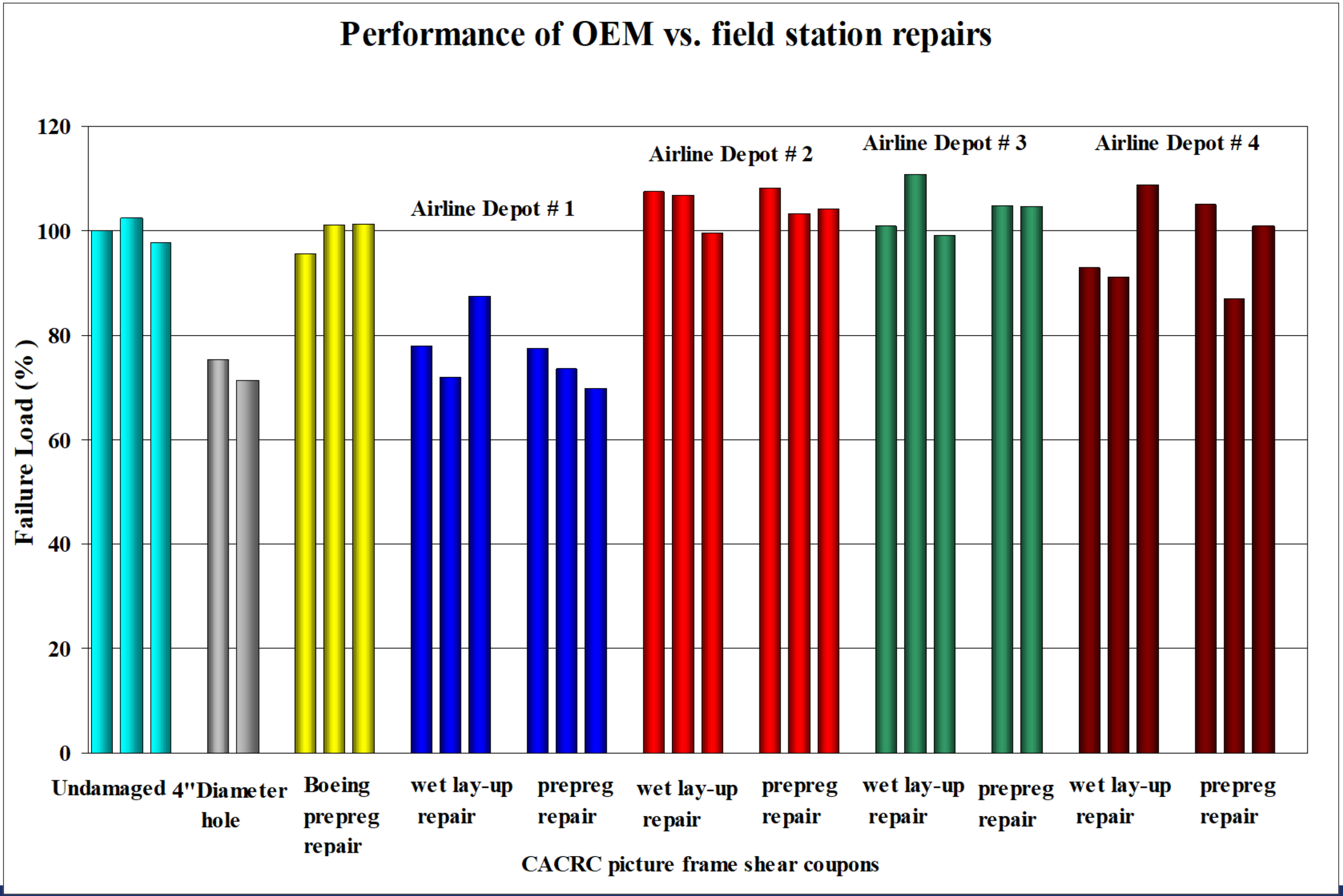
Repair test results

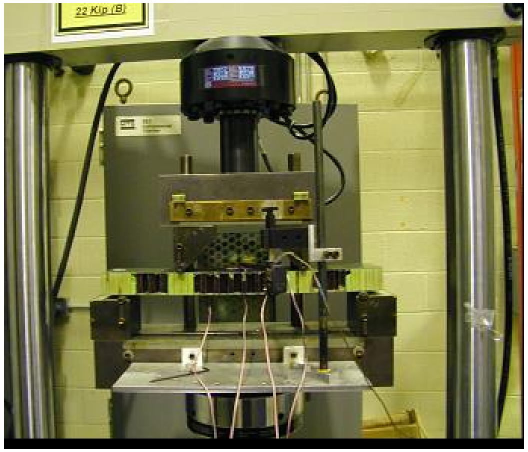


Repair variables investigation

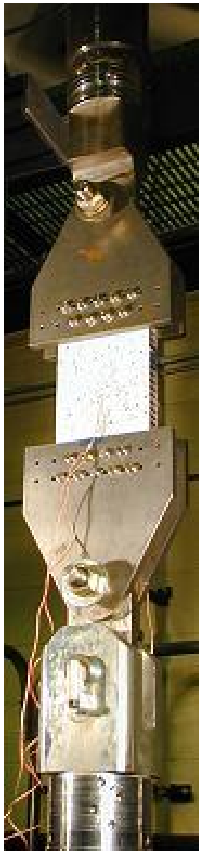
- Scarf ratios
- Core size
- 1-D and 2-D repairs
- Tension (tensile load and flexure), compression (flexure) and limited number of impacts
- Primarily used to “exercise” analytical model

Repair variables investigation

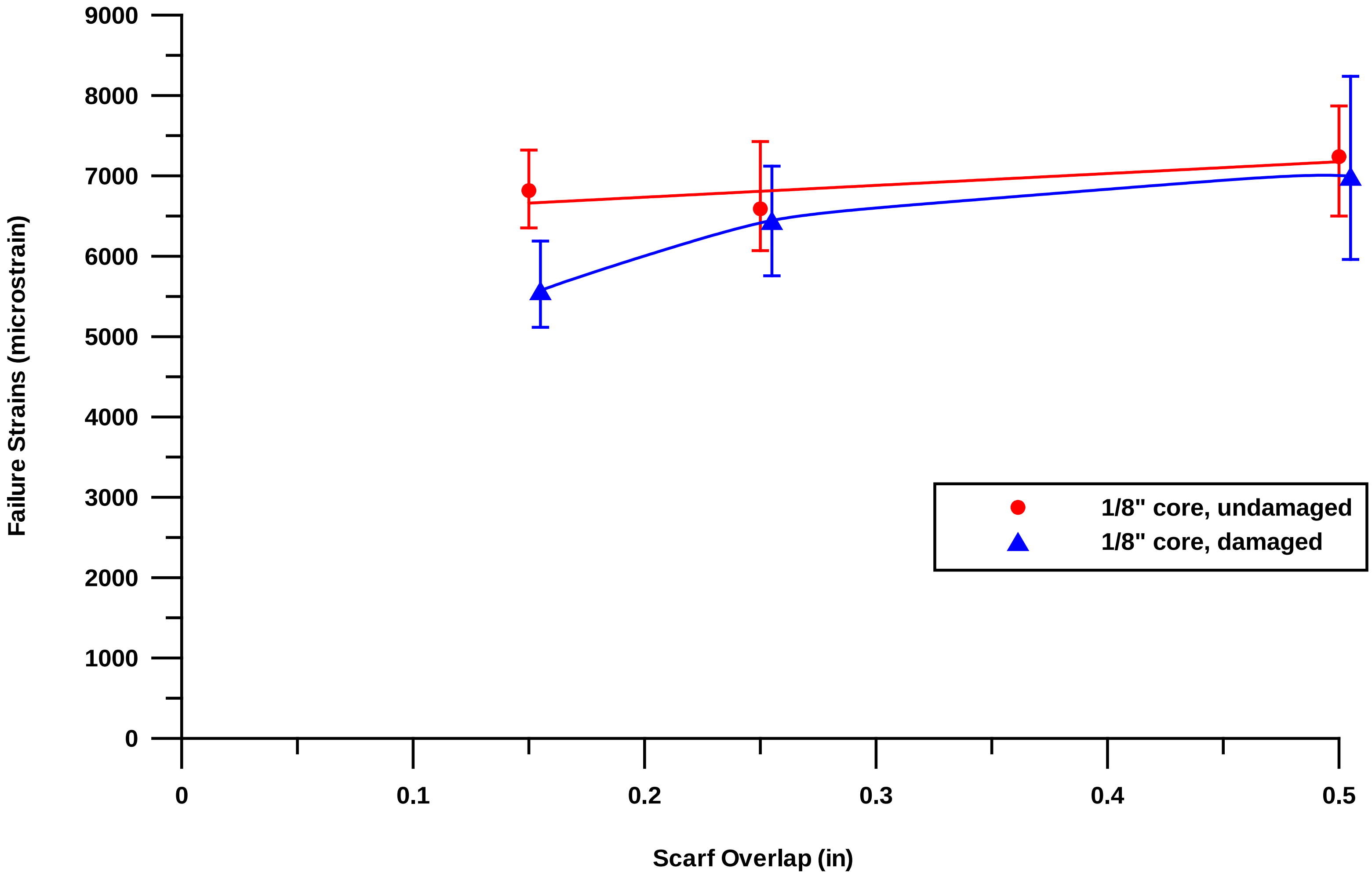
Large (11.5”X46”) and small (14”X3”) Four-Point Bending Beams



Unidirectional Tension Coupons



Scarf overlap results



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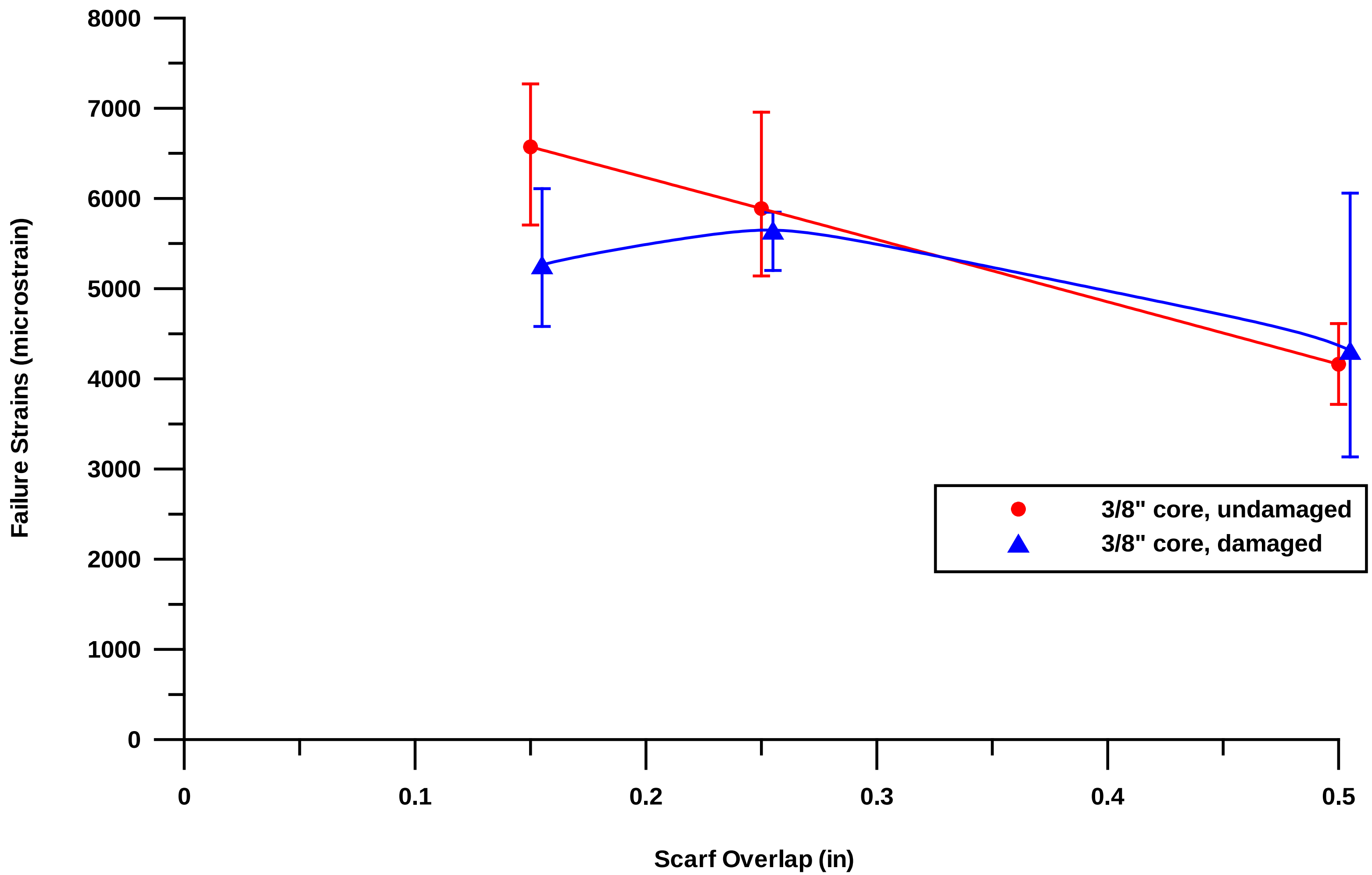
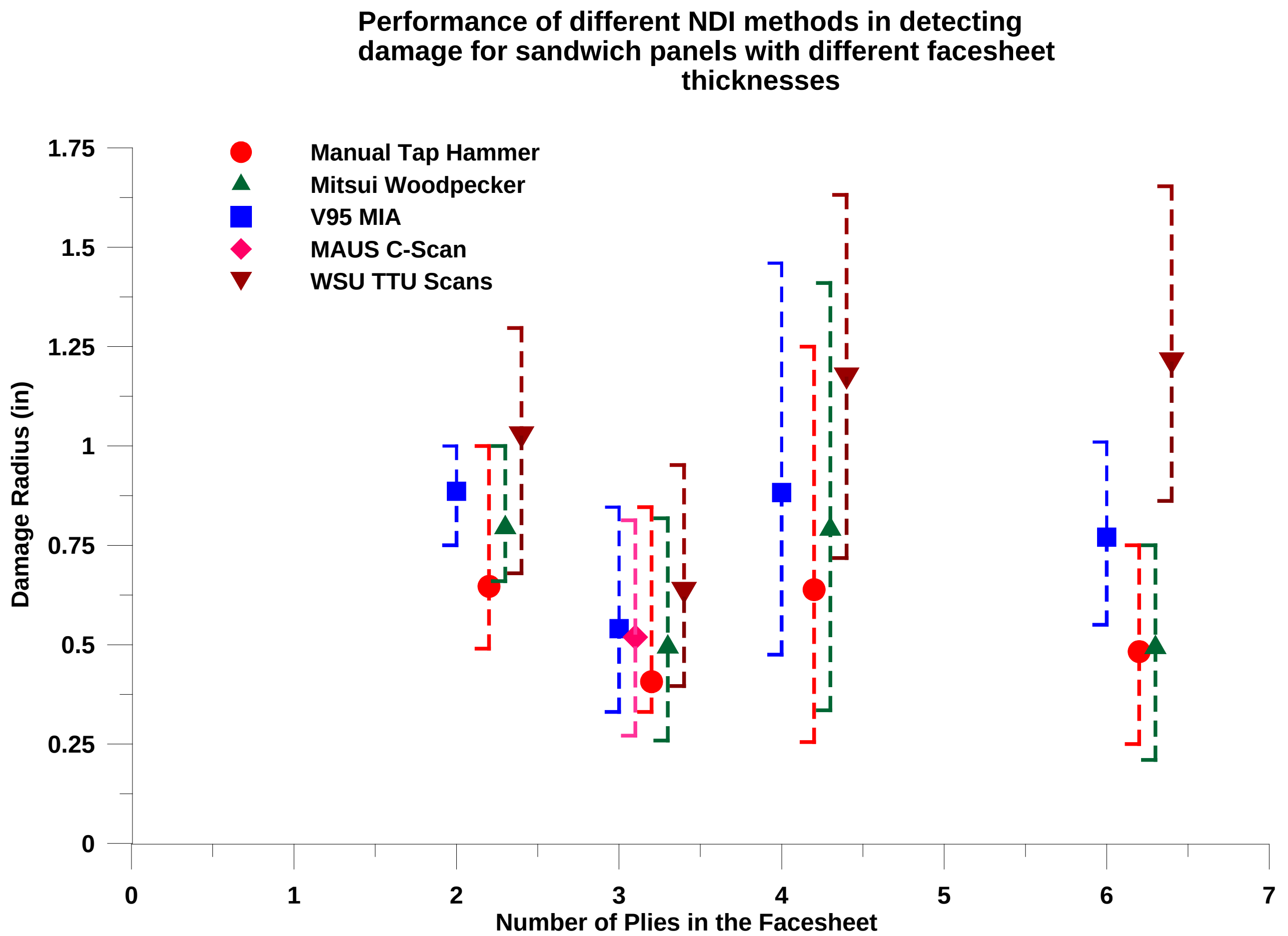
Scarf overlap results



NDI results


Performance of different NDI methods in detecting damage for sandwich panels with different facesheet thicknesses
Manual Tap Hammer
Mitsui Woodpecker
V95 MIA
MAUS C-Scan
WSU TTU Scans
Damage Radius (in)
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0
1
2
3
4
5
6
7
Number of Plies in the Facesheet

NDI conclusions

- All the NDI field methods underestimated the damage size with the tap hammer being the least conservative
- Thickness seems to be a factor, however, the range here is only 2 to 6 plies
- The smaller the damage the better field techniques are
- Limitations of field NDI must be understood; this must be taken into account when deciding on the applicable damage size in the SRM

Repair study conclusions

- All the repaired picture frame shear elements restored at least 90% of the average pristine strength except elements from one airline depot
- Heat blanket failure equals repair failure
- Field repair equivalent to prepreg repair
- Successful repairs require trained personnel
- The core cell size had a major effect on the performance of repaired sandwich structures regardless of the material system used: 1/8” core sandwich structures have higher strength than with the 3/8” core
- Comparable results can be achieved by either a 0.25” or a 0.5” scarf overlap
- Analysis has difficulty modeling core/face-sheet interfaces.

Future work - repair

- Effects of poor repair procedures on repair integrity
  - Low pressure
  - Low cure temperature
  - Contaminants
  - Pre-bond moisture
- To validate existing CACRC standards and provide recommendations pertaining to proper repair process implementation
- To develop an analysis method and corresponding failure criteria for structural sizing of bonded repairs

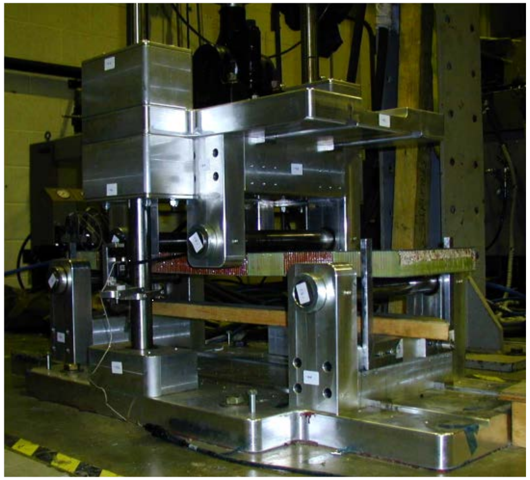
Research methodology

- Task1: to generate baseline static and fatigue repair data sandwich coupons using OEM repairs as well as field repairs. Repaired coupons are tested in compression.

- Task 2: to evaluate the durability of “poor” bonded repairs that passed NDI (undetected weak repairs). Deviations in process parameters/ contamination will be induced during coupon repair and subsequent mechanical testing will be conducted to assess the static and residual strength after repeated loading.

- Task 3: task 2 results will be used to validate CACRC standards required for composite repair and inspection technicians and providing recommendations pertaining to repair process control to ensure repair bond structural integrity

- Task 4: to validate experimental results using FEM.



Baseline test matrix

- 45 coupons will be used to generate baseline static and fatigue data for OEM/ field repairs
- A four point bending beam fixture will be used for loading
- Fatigue coupons will be cycled for one lifetime equivalent to 150000 cycles and tested for residual strength to demonstrate repair acceptability.

Repair Configuration	Core Cell Size	Repair Material	Repair Type	Scarf Overlap (in)	Static (RTA)	Fatigue (RTA)
2-D Compression	3/16	Toray T700/2510 PW Prepreg	Baseline undamaged	N/A*	3	6
			Flush Scarf Repair	0.50	3	6
			External Patch	0.50	3	6
	3/16	CACRC Wet lay-up Repair	Flush Scarf Repair	0.50	3	6
			External Patch	0.50	3	6

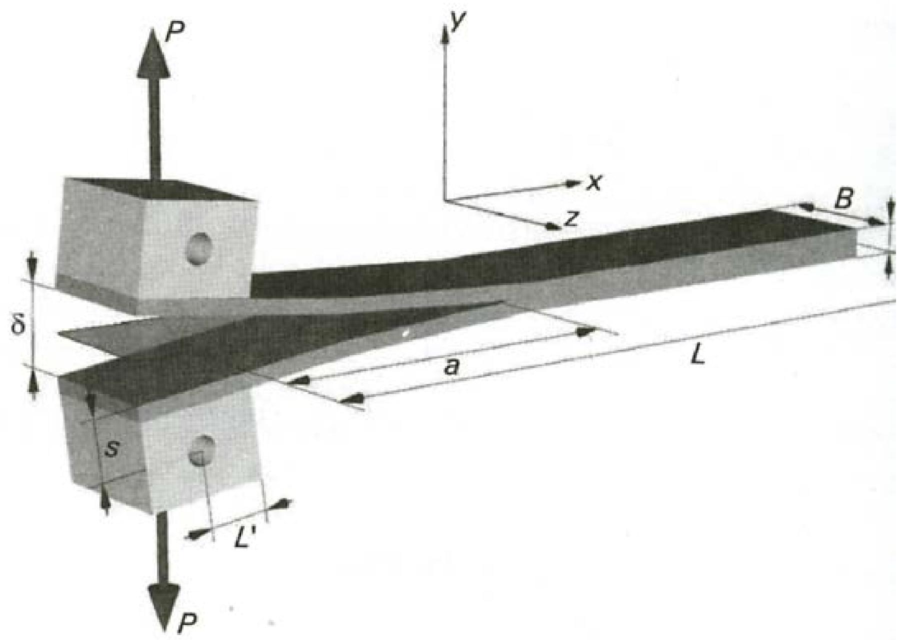
*Baseline undamaged unrepaired coupon

Screening test matrix to determine worst contaminants

- A surface with a high surface free energy will produce a good bond
- Surface free energy can be measured by measuring surface contact angle
- Screening study was conducted to determine surface free energy of contaminated surfaces ready for repair (Dr. Bill Stevenson)

Contaminant	Exposure	Surface Free Energy (mN/m)
None	N/A	55.16
Deicing Fluid	30 days @ RTD	56.29
Skydrol	30 days @ RTD	43.83
Jet Fuel JP-8	30 days @ RTD	51.74
Water (85% @145°F)	Saturation	46.4
Salt Water	30 days@ RTD	56.41

Test for surface preparation adequacy



DCB Test Specimen

Effects of process parameters- test matrix

➢ **Based upon the screening tests, mechanical tests will be conducted to assess the effects of process deviations on these repairs**

Load Mode	Process Parameters	Laminate Thickness	Scarf Rate	Quantity of Test OEM Repair Static (RTA)	Quantity of Test OEM Repair Repeated Loading (RTA)
Tension	Effects of Poor Surface Preparation	0.1332	20	6	6
		0.2368	20	6	6
	Effects of Improper Cure	0.1332	20	6	6
		0.2368	20	6	6
	Effects of Surface Contaminant 1	0.1332	20	6	6
		0.2368	20	6	6
	Effects of Surface Contaminant 2	0.1332	20	6	6
		0.2368	20	6	6
	Effects of Pre-bond Moisture	0.1332	20	6	6
		0.2368	20	6	6

Reference reports

- “Review of Damage Tolerance for Composite Sandwich Airframe Structures,” DOT/FAA/AR-99/49, August 1999.
- “Imaging Flaws in Composite Honeycomb Aircraft Structures Using Instrumented Tap Test,” SPIE Proceedings on Nondestructive Evaluation of Aging Materials and Composites, Vol. 3585, 1999. pp. 236-245.
- “Damage Tolerance of Composite Sandwich Structures,” DOT/FAA/AR-99/91, January 2000.
- “Impact Damage Characterization and Damage Tolerance of Composite Sandwich Airframe Structures,” DOT/FAA/AR-00/44, January 2001.
- “Damage Resistance Characterization of Sandwich Composites Using Response Surfaces”, DOT/FAA/AR-01/71, March 2002.
- “Impact Damage Characterization and Damage Tolerance of Composite Sandwich Airframe Structures – Phase II,” Final Report, DOT/FAA/AR-02/80, September 2002.
- “Damage Tolerance Characterization of Sandwich Composites Using Response Surfaces”, DOT/FAA/AR-02/101, October 2002.

- “Damage Tolerance Characterization of Sandwich Composites Using Response Surfaces”, DOT/FAA/AR-02/101, October 2002.

- “Bonded Repair of Aircraft Composite Sandwich Structures”, DOT/FAA/AR-03/74, February 2004.
- “Guidelines for Analysis, Testing, and Nondestructive Inspection of Impact Damaged Composite Sandwich Structures,” DOT/FAA/AR-02/121, March 2003.
- “Damage Resistance and Tolerance of Composite Sandwich Panels- Scaling Effects”, DOT/FAA/AR-03/75, February 2004.
- “Damage Tolerance of Composite Sandwich Airframe Structures-Additional Results”, DOT/FAA/AR-05/33, October 2005.

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