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CACRC Depot Bonded Repair Round Robin Investigation

John Tomblin and Lamia Salah

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CACRC Depot Bonded Repair Investigation

- **Principal Investigators & Researchers**

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- **FAA Technical Monitors**

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- **Other FAA Personnel**

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- **Industry Participation**

  Spirit Aerosystems – John Welch, Brian Kitt, Mike Borgman, Ming C. Liu, Jeff Dempsey

  Boeing – Russell Keller

  Airbus – Francois Museux

  Lufthansa Technik AG – Jan Popp

  Delta/Northwest Airlines – Ray Kaiser, Nathan Schulz

  United Airlines/Continental – Eric Chesmar, Dean Jerry

  Nordam – Paul Creider

  Aviation Technology Associates – Marc Felice

  Hexcel – Justin Hamilton

  Sandia National Laboratories – Dennis Roach Ph.D., Stephen Neigdik

Introduction – Technological Challenges

In-Service Damage, Courtesy Eric Chesmar, UAL [1]

Motivation/ Key Issues

- Major Technological Advances using Composite Materials in the last 50 years (composite materials used for the first time in wing and fuselage load bearing structures)

Technological Challenges

- Material fabrication and Processes, analysis methods, structural health monitoring, lightning strike protection, recycling, repair methods and standardization

Important Considerations for continued airworthiness [2]

- Durability, environmental resistance (Brittle nature of polymers, weak interfacial bonds)
- Repairability, supportability (development of repair methods, in-service maintenance versus OEM environment, chemical and mechanical properties of materials)
- Maintainability (simple assemblies, easy access to hardware, clearly defined ADL,CDT early development of repair methods)

References:

1. **Chesmar, E., "Repair And Maintenance Implementation: Airline Experience, Problems, Concerns and Issues," Presented at FAA Bonded Workshop, 2004.**
2. **Design of Durable, Repairable and Maintainable Aircraft Components – SAE AE 27, 1997**

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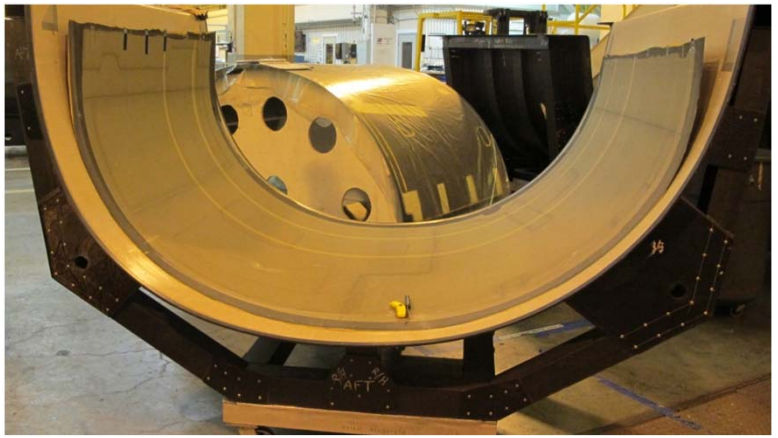
Introduction – In Service Experience

Lessons Learned:

- Outstanding performance where reliable processes were used
- Numerous in-service failure with deficient processes
- Surface preparation yielding a clean chemically active interface resistant to degradation is necessary for a durable bond

- Adhesion failures are caused by deficient processes (pre-bond contamination, poor surface preparation, inadequate cure parameters that inhibit the formation of strong chemical bonds)
- Cohesion Failures are caused by poor design (thermal residual stresses, stiffness mismatch between adherends, poor material selection, inadequate repair overlap, porous bondlines)

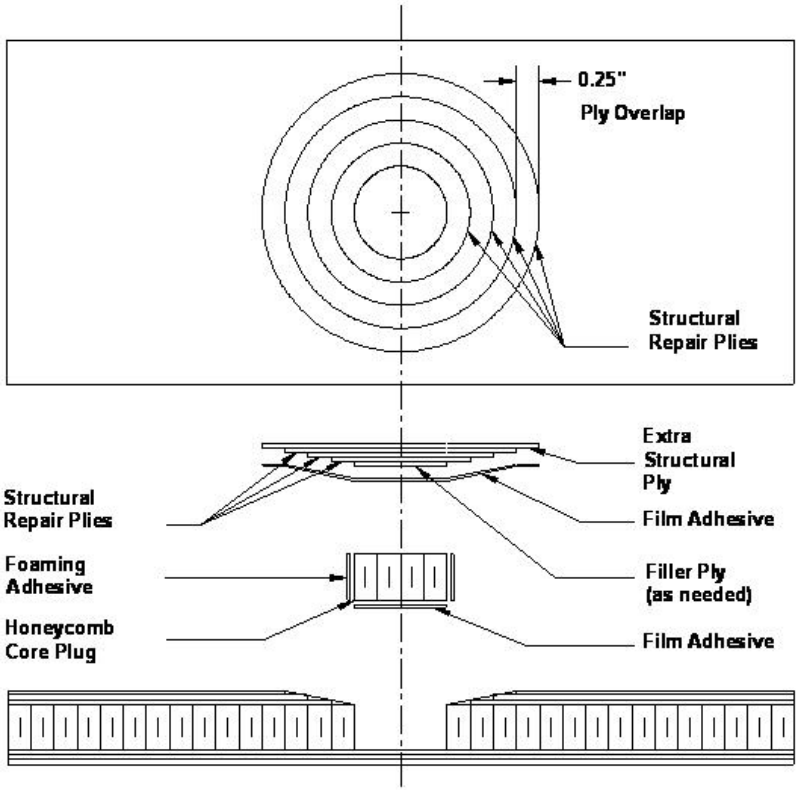
- NDI methods cannot guarantee absolute bond integrity
- Rigorous bond quality management and process execution is necessary



Complete Overhaul of a Composite Fan Cowl

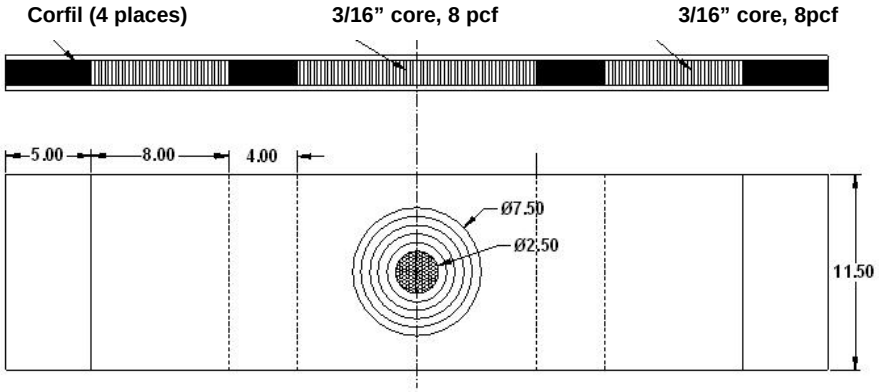
Research Objectives

- To evaluate the existing CACRC standards and approved materials used for repair of composite structures
- To assess the repair process variability between depots, using the same SRM-like procedures (using CACRC repair techniques and materials) provided to all the depots
- To investigate the variability associated with technician training (minimal level of experience versus extensive experience) on the performance of the repair
- To compare strength of the different repairs (CACRC-R1/R2 field repairs vs OEM-R1/R2 repairs) to a set of control “pristine” panels and to a set of open-hole panels
- To evaluate the environmental effects on the static and residual strength after fatigue of these repairs

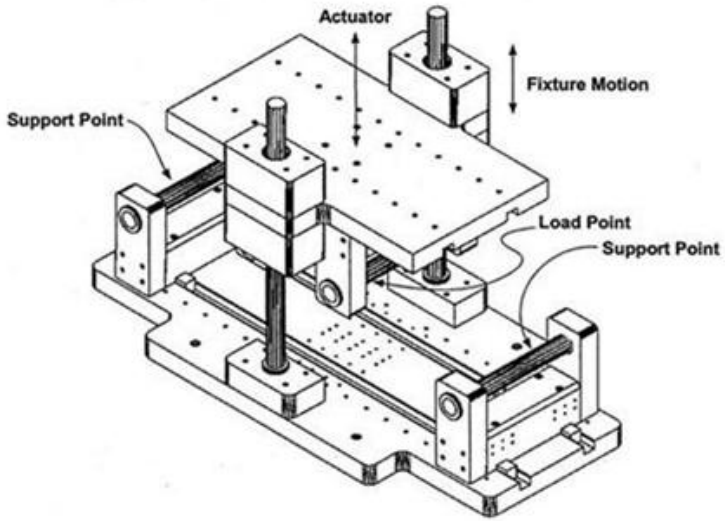


Bonded Repair to a sandwich panel

Research Approach/ Methodology



Sandwich Repair Element Configuration



Four-Point Flexure Fixture

Sandwich Specimen Configuration
Representative of production materials and processes

- Large beams, 11.5" x 48" with the repair tested in compression and tension modes
- 2.5" hole diameter to maintain a W/D>4
- 2" thick core, 3/16" core cell size, 8 pcf, 4-ply facesheets

Parent Material:
T300/ 934 3KPW with FM 377S adhesive (OEM)

Repair Materials:
CACRC repair 1: Hexcel M20 PW (250°F cure) with EA9695 adhesive (AMS 3970)

CACRC repair 2 (wet lay-up): Tenax HTA 5131 200tex f3000t0 fabric with Epocast 52A/B laminating resin (AMS 2980)

OEM repair 1: using the parent system (350°F cure)

OEM repair 2 (wet lay-up): Tenax HTA 5131 200tex f3000t0 fabric with EA9396 C2 laminating resin and EA9696 adhesive

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Test Matrix

Repair Station	Coupon Configuration	Repair Material	Loading Mode	Experience Level	Static RTA	Static ETW	Fatigue ETW
N/A	Pristine/ Undamaged	N/A	Compression		3	3	3
N/A	2.5" hole	N/A- Open Hole	Compression			3	3
OEM/ NIAR	Repair/ 2.5" hole	OEM-R1	Compression			3	3
OEM/ NIAR	Repair/ 2.5" hole	OEM-R2	Compression			3	3
OEM/ NIAR	Repair/ 2.5" hole	OEM-R2	Tension			3	3
OEM/ NIAR	Repair/ 2.5" hole	CACRC-R1	Compression			3	3
OEM/ NIAR	Repair/ 2.5" hole	CACRC-R1	Tension			3	3
OEM/ NIAR	Repair/ 2.5" hole	CACRC-R2	Compression			3	3
OEM/ NIAR	Repair/ 2.5" hole	CACRC-R2	Tension			3	3
Field Station 1	Repair/ 2.5" hole	CACRC-R1	Compression	M1		3	
Field Station 1	Repair/ 2.5" hole	CACRC-R2	Compression	M1		3	
Field Station 1	Repair/ 2.5" hole	CACRC-R1	Compression	M2		3	
Field Station 1	Repair/ 2.5" hole	CACRC-R2	Compression	M2		3	
Field Station 2	Repair/ 2.5" hole	CACRC-R1	Compression	M1		3	
Field Station 2	Repair/ 2.5" hole	CACRC-R2	Compression	M1		3	
Field Station 2	Repair/ 2.5" hole	CACRC-R1	Compression	M2		3	
Field Station 2	Repair/ 2.5" hole	CACRC-R2	Compression	M2		3	
Field Station 3	Repair/ 2.5" hole	CACRC-R1	Compression	M1		3	
Field Station 3	Repair/ 2.5" hole	CACRC-R2	Compression	M1		3	
Field Station 3	Repair/ 2.5" hole	CACRC-R1	Compression	M2		3	
Field Station 3	Repair/ 2.5" hole	CACRC-R2	Compression	M2		3	
Field Station 4	Repair/ 2.5" hole	CACRC-R1	Compression	M1		3	
Field Station 4	Repair/ 2.5" hole	CACRC-R2	Compression	M1		3	
Field Station 4	Repair/ 2.5" hole	CACRC-R1	Compression	M2		3	
Field Station 4	Repair/ 2.5" hole	CACRC-R2	Compression	M2		3	
Field Station 5	Repair/ 2.5" hole	CACRC-R1	Compression	M1		3	
Field Station 5	Repair/ 2.5" hole	CACRC-R2	Compression	M1		3	
Field Station 5	Repair/ 2.5" hole	CACRC-R1	Compression	M2		3	
Field Station 5	Repair/ 2.5" hole	CACRC-R2	Compression	M2		3	
							117

OEM-R1	T300/934 w FM377 adhesive
OEM-R2	EA 9396 C2 wet lay-up w EA9696
CACRC- R1	M20PW with EA9695 adhesive
CACRC- R2	Epocast 52A/B wet lay-up

M1	Minimal level of Experience
M2	Experienced Mechanic

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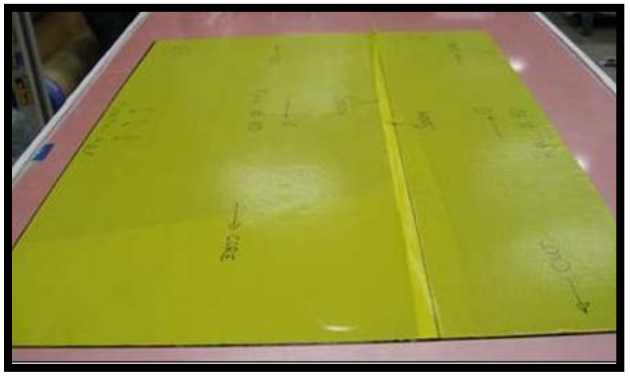
Research Methodology – Parent Panel Manufacture Assembly 1

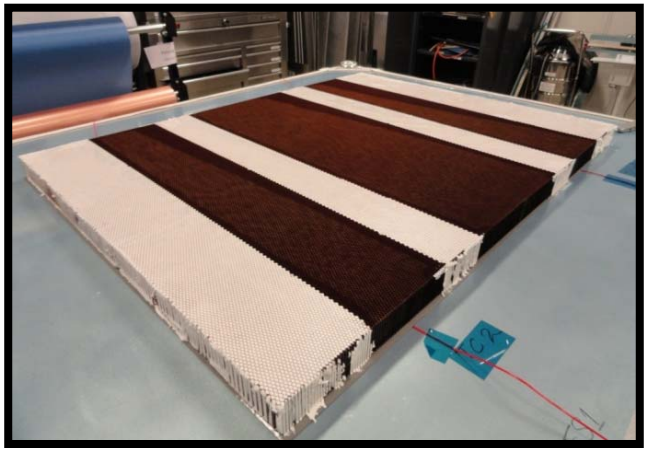
- Parent materials provided by the OEM
- Panel manufacture conducted at NIAR/NCAT using OEM approved processes (40 large panels)



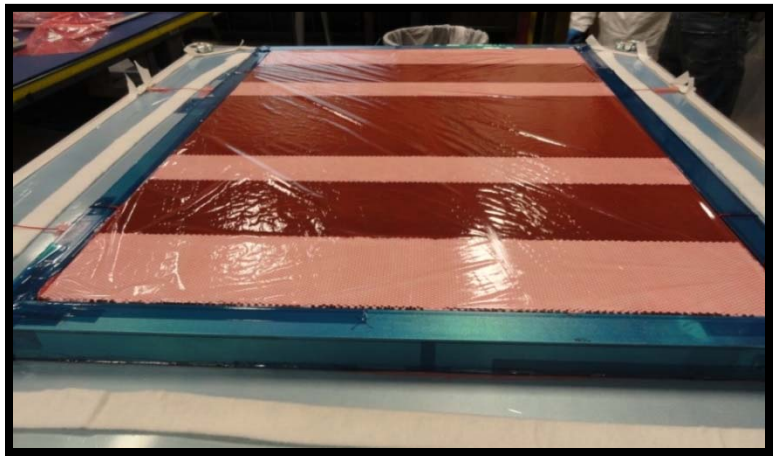
Facesheet 1 lay-up

Film Adhesive Application

Corfill Application

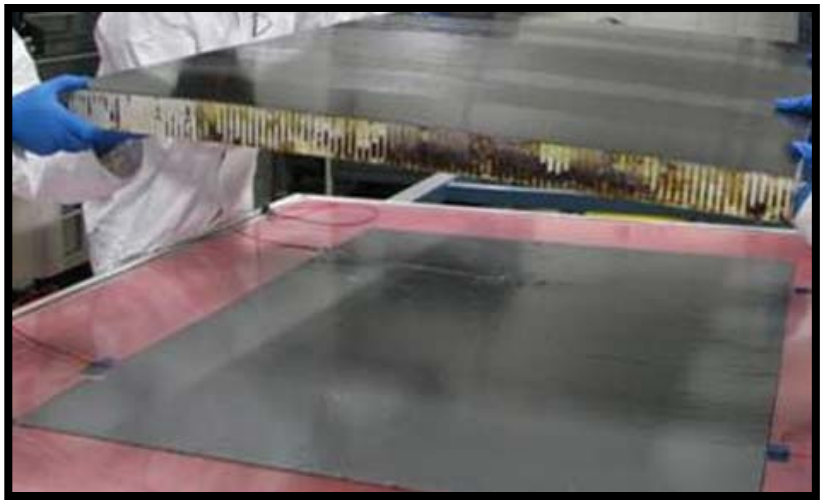


Core Application onto facesheet 1

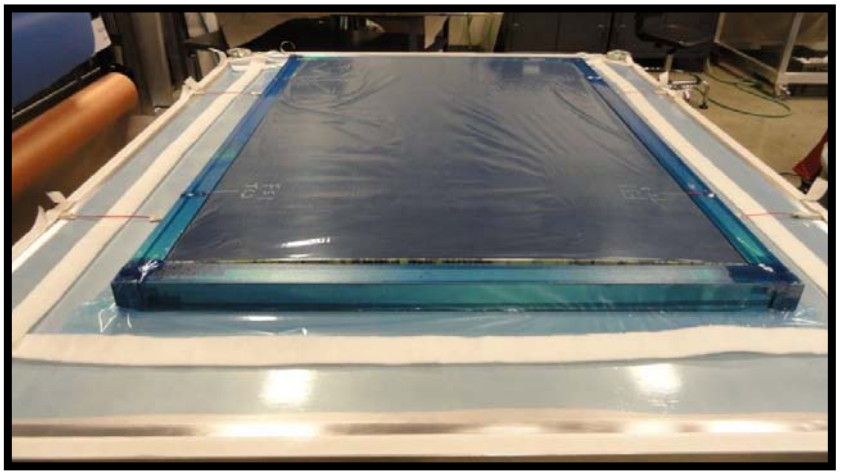


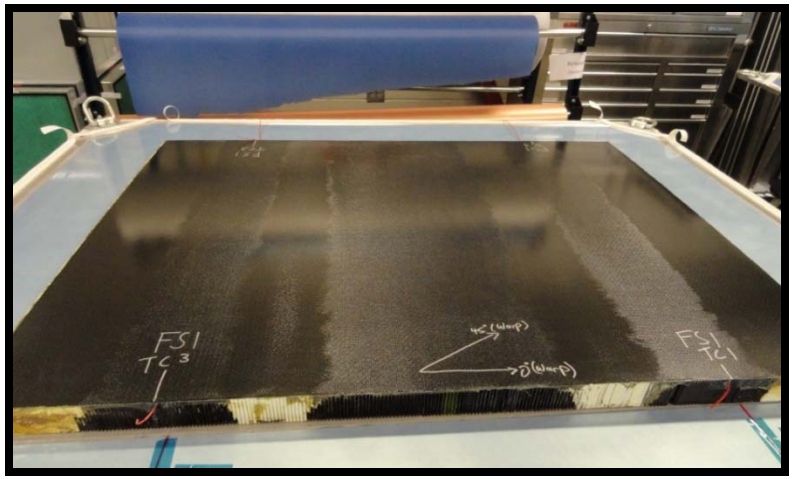
Assembly 1 Bagging and preparation for cure

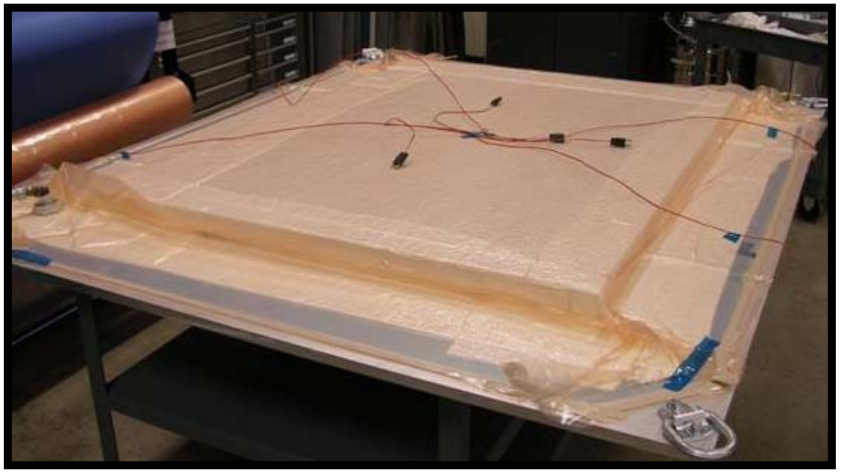
Research Methodology – Parent Panel Manufacture Assembly II



Uncured Assembly 2 (facesheet 2 and adhesive) co-bonded to cured assembly 1

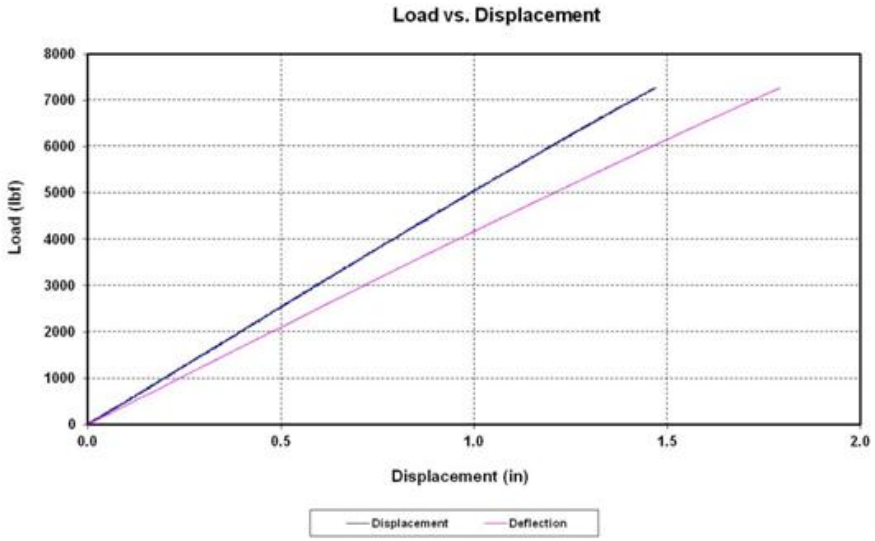


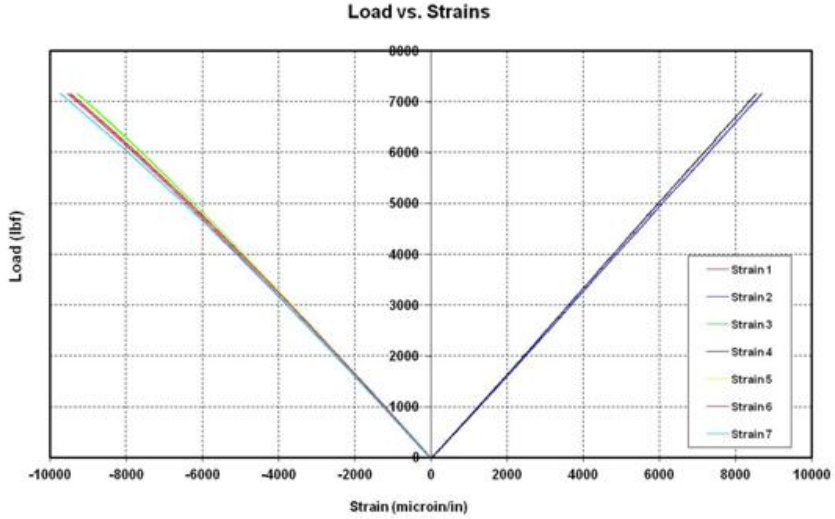




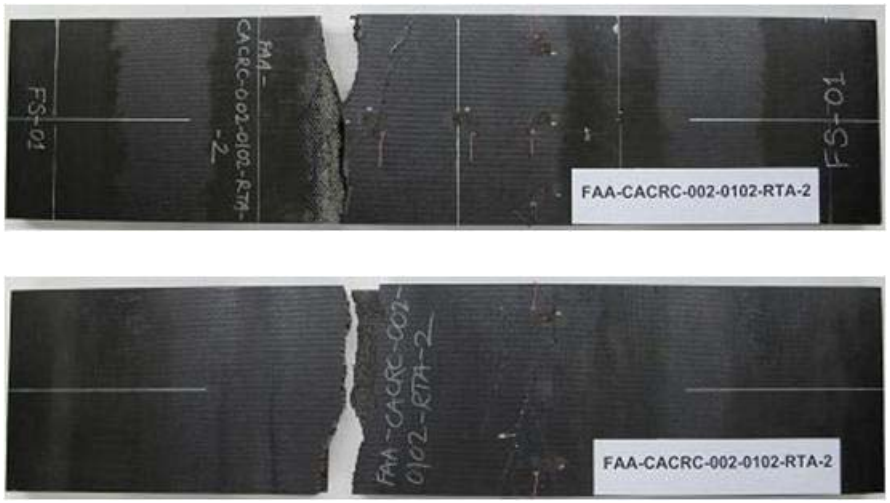
Assembly Bagging in preparation for cure

Research Methodology – Sandwich Element Design Validation



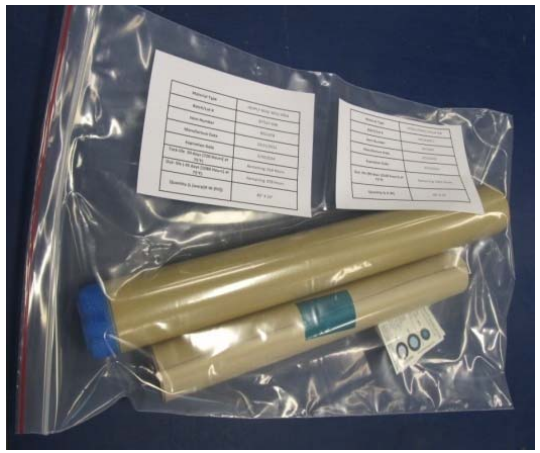


- 3 undamaged-pristine beams were tested to establish the undamaged parent element capability
- Good correlation between experimental results and predictions
- Average failure strains (-9335με -compression and 8492με -tension)



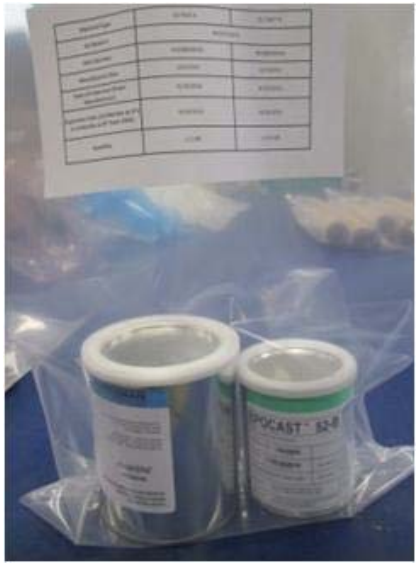
Typical Failure Mode – Undamaged beams

Repair Procedure and Kit preparation



CACRC Prepreg Kit

- A detailed SRM like repair procedure referencing the relevant SAE CACRC standards was reviewed and approved by the technical monitors, industry POCs and participating airline depots before performing the repairs
- Repair process checklists with inspection points for both wet lay-up and prepreg repairs were provided to the repair personnel along with the CACRC standards (detailed process documentation)



CACRC Wet Lay-Up Resin

Repair kits (using CACRC approved materials) were prepared and shipped to all participating depots

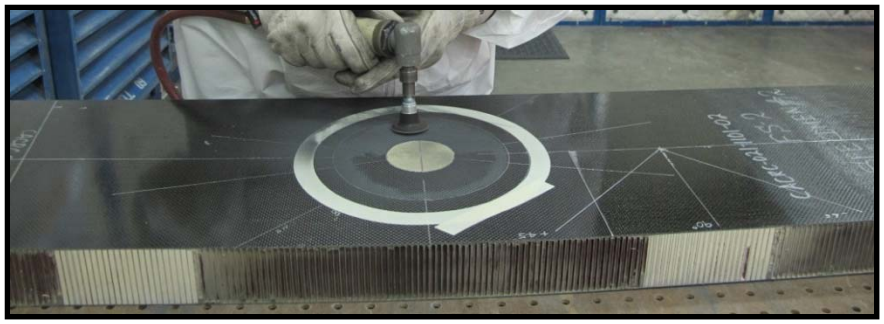
- Hexcel M20/G904 prepreg
- EA9695 NW 0.05 psf film adhesive
- Hexcel G904 D1070 TCT, PW dry fabric, 193 g/m^2 using Tenax Fibers
- Huntsmann Epocast 52A/B resin
- Peel ply and perforated film for wet lay-up bagging

Notes:

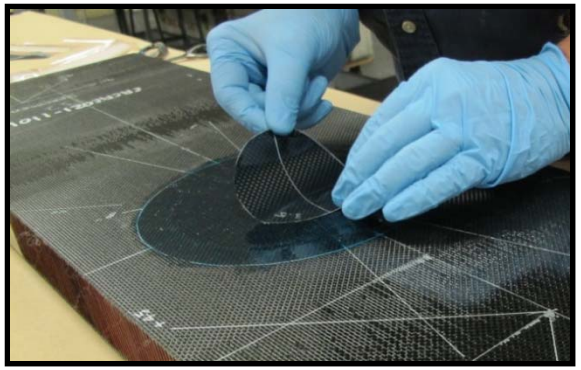
- Difficulties in material procurement, long lead times and difficulty obtaining small quantities
- Materials not commonly used in composite repairs

CACRC Repairs - Depot #1

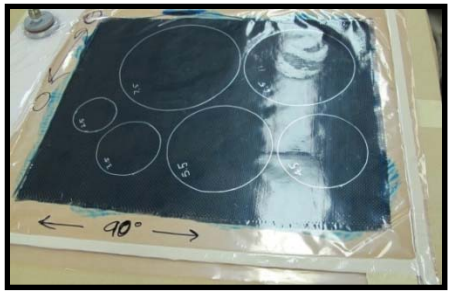
CACRC Repair Element Masking in Preparation for Scarf Sanding



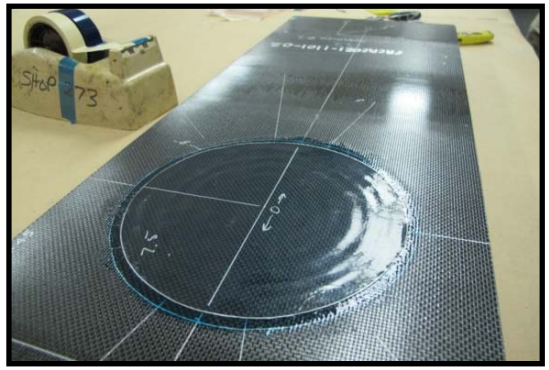
Scarf/Taper Sanding



Wet lay-up repair ply application



Wet lay-up resin impregnation



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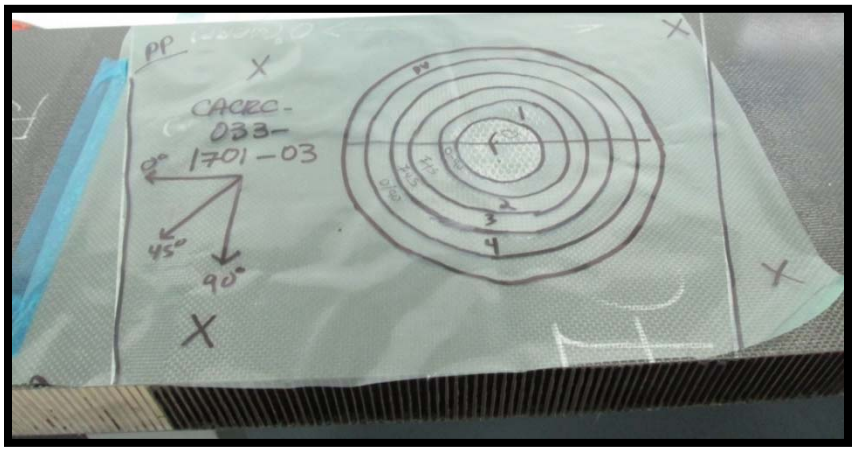
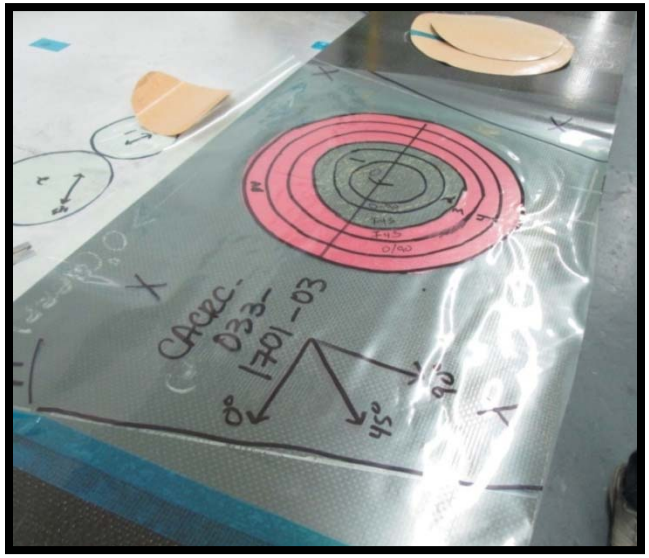
CACRC Repairs - Depot #2

Element scarf sanded in preparation for repair



Repair Ply Template

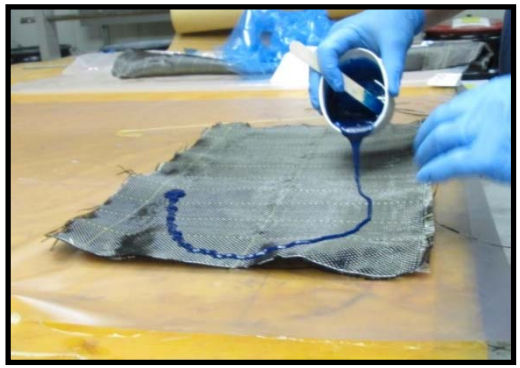


Repair Ply Application

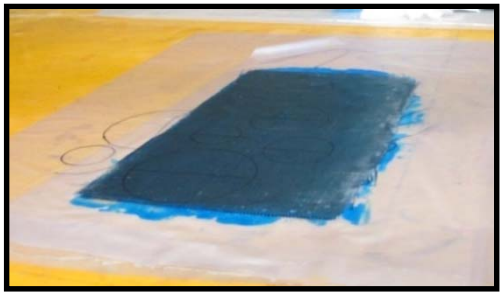
Cured Repair

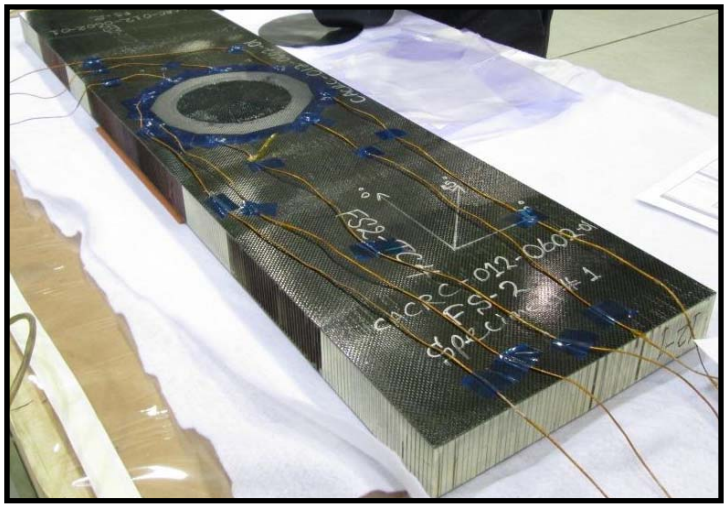
CACRC Repairs - Depot #3

Element scarf sanded in preparation for repair

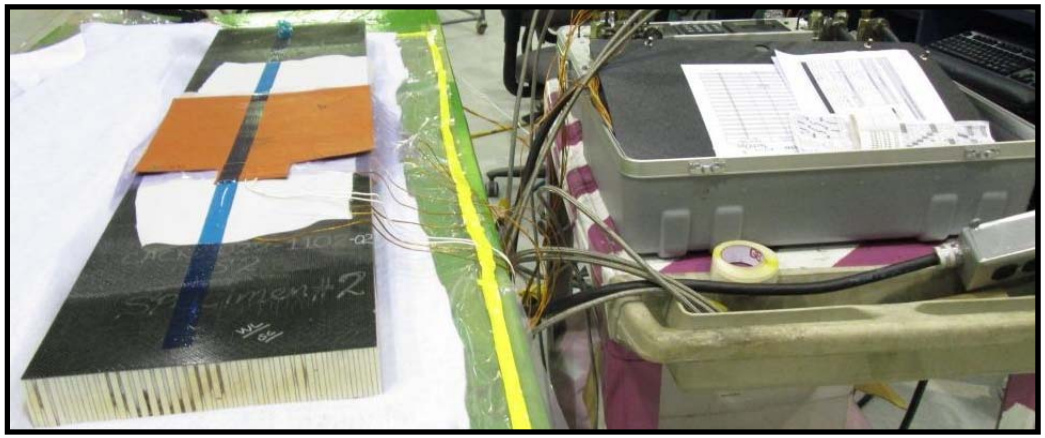


Wet lay-up resin impregnation





Wet lay-up repair application



Repair Bagging in preparation for cure

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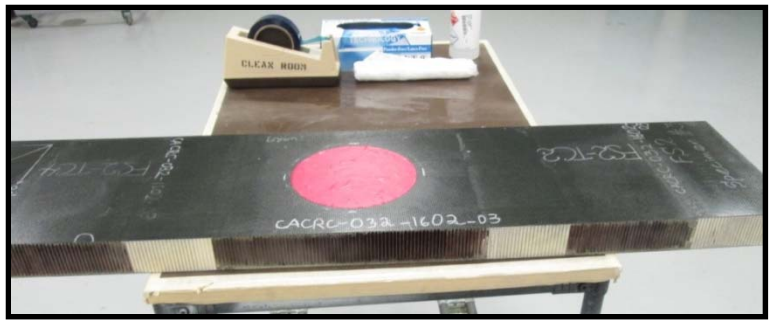
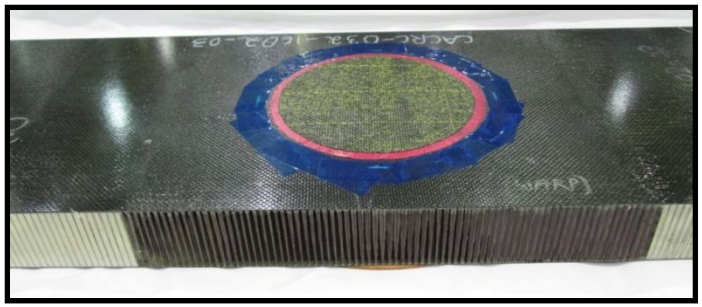
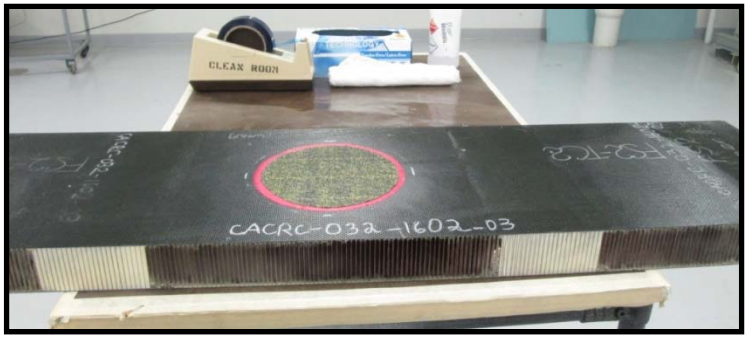
CACRC Repairs - Depot #3



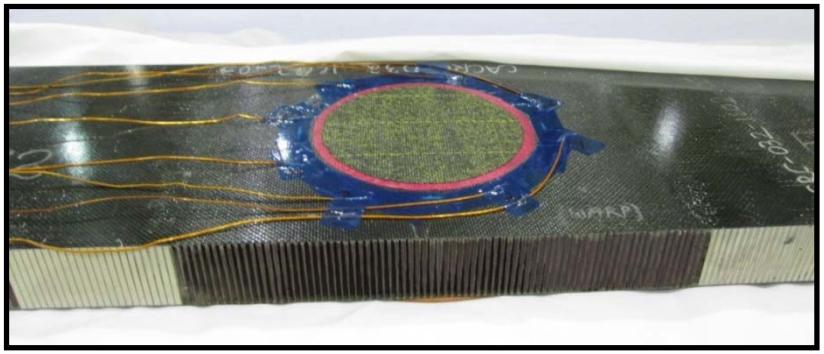
Adhesive application – prepreg repair



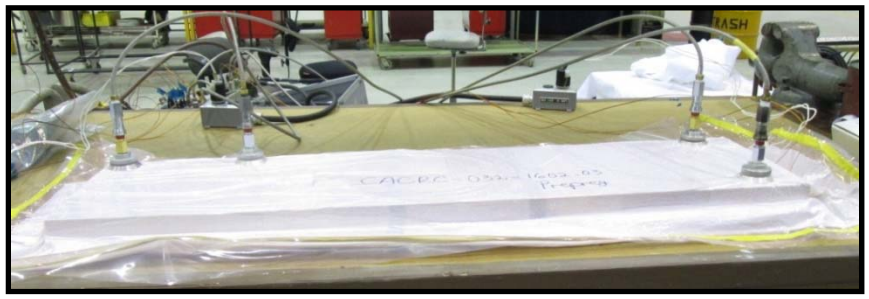
Repair Masking – prepreg repair



Repair application – prepreg repair



Thermocouple Application – prepreg repair

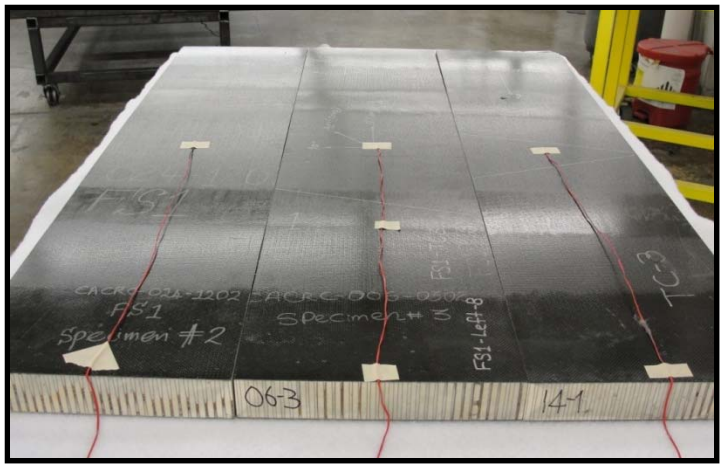


Repair Bagging

Cured repair

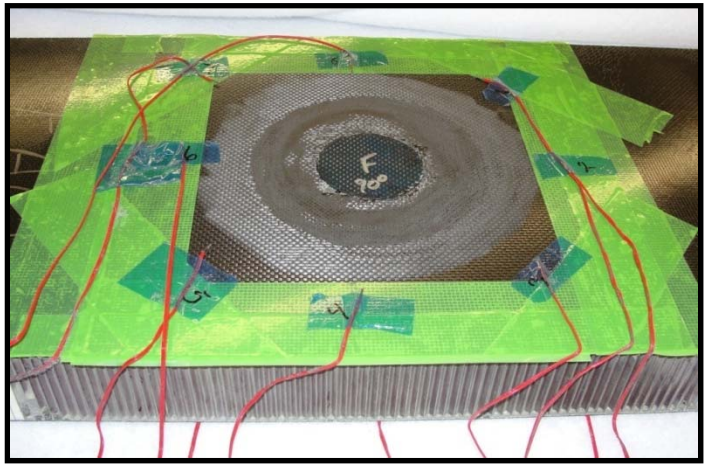
CACRC Repairs - Depot #4

Repair Element Scarf Sanded in Preparation for Repair



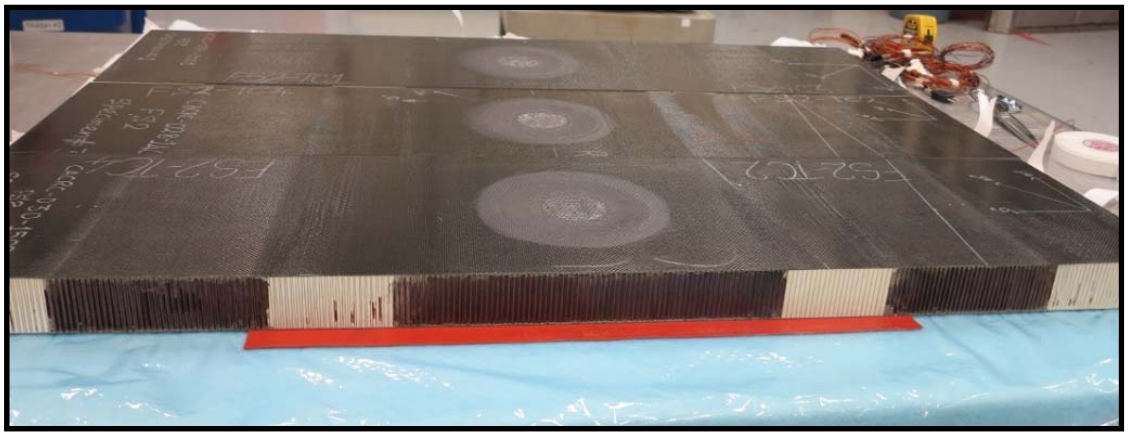
Repair Elements Scarfed and prepared for Drying

Repair Element Drying

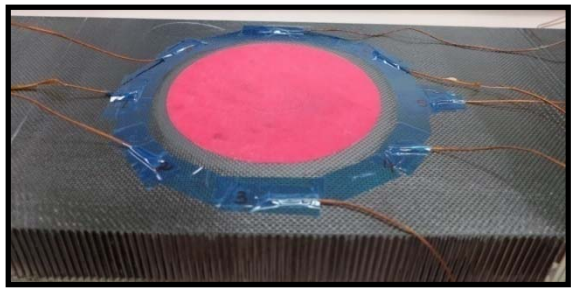


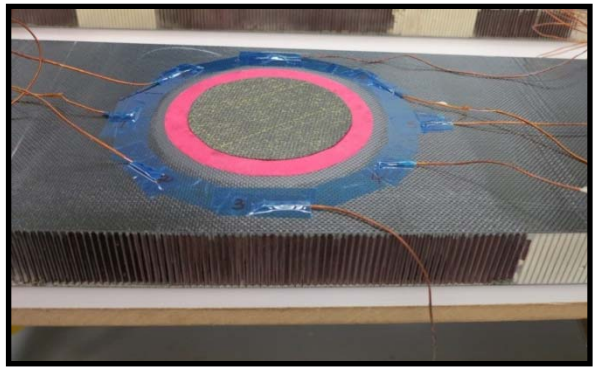
Repair Application

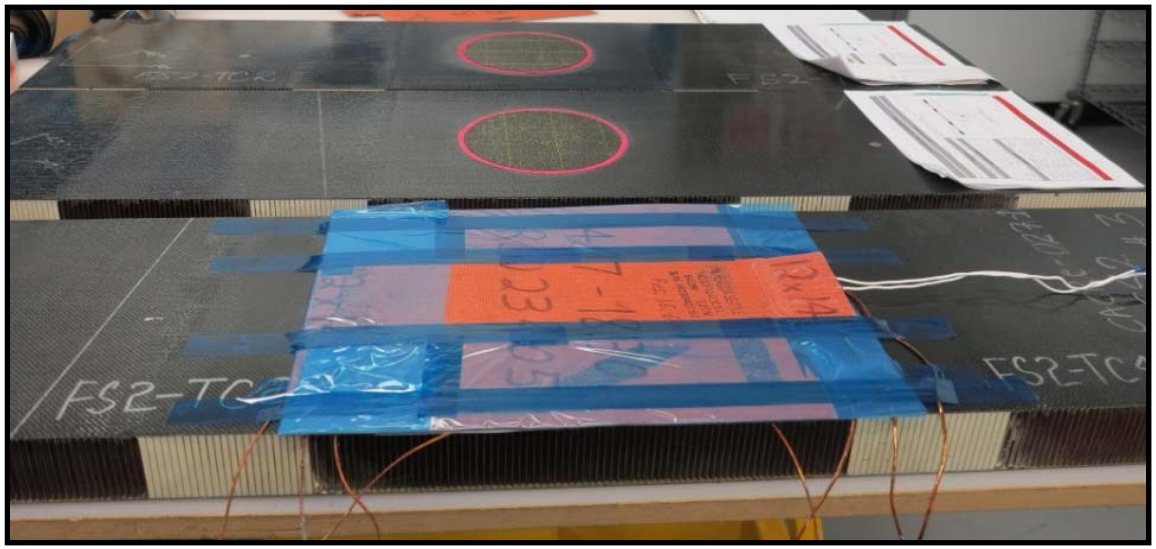
CACRC Repairs - Depot #5



Scarfed Elements prepared for drying



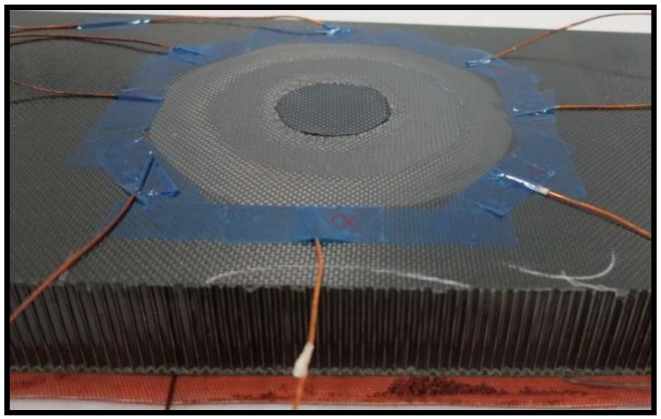




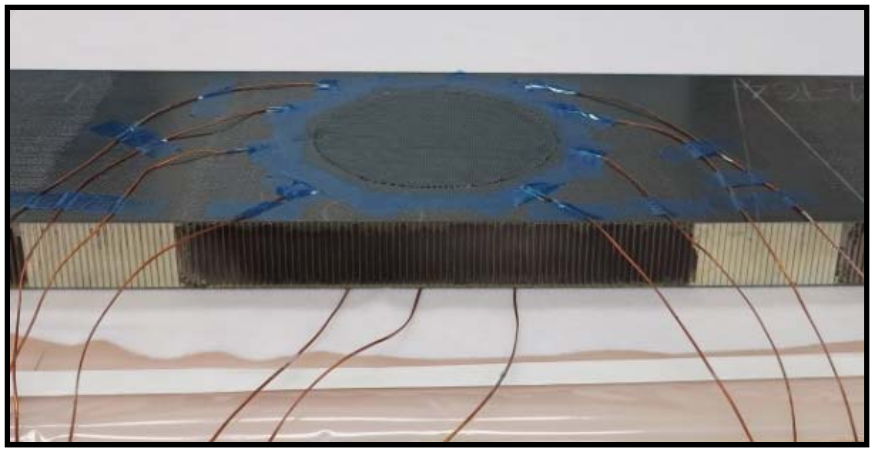
Prepreg Repair Application

CACRC Repairs - Depot #5

Wet lay-up ply impregnation



Wet lay-up repair application



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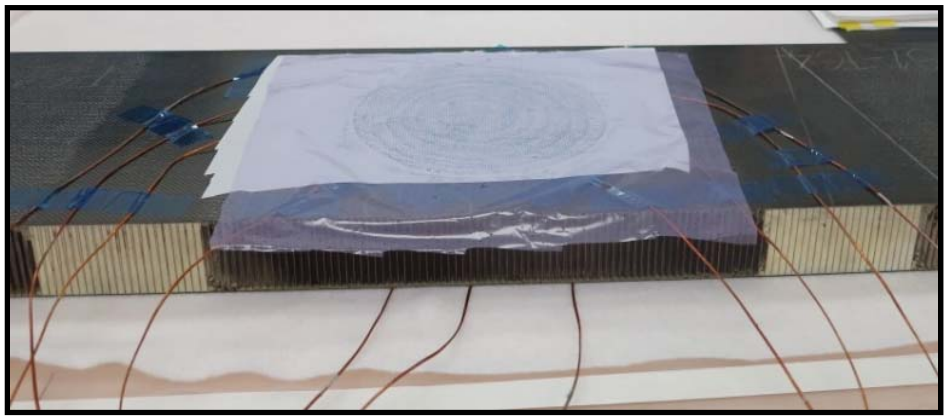
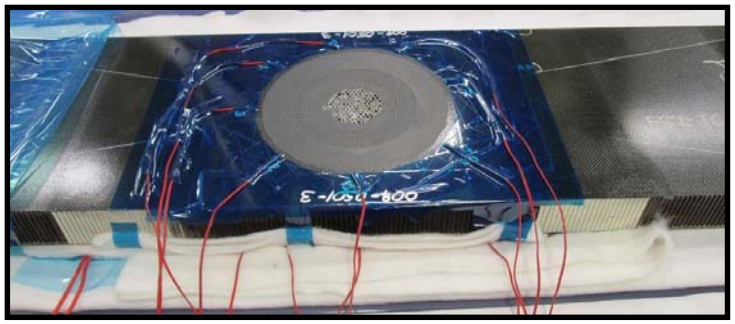
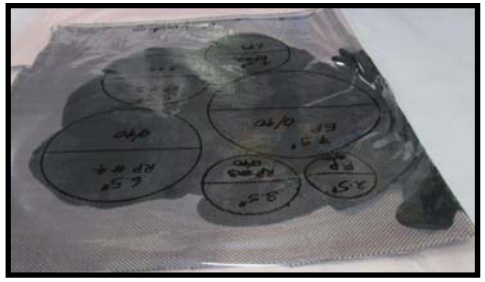


Wet lay-up repair bagging in preparation for cure

OEM Wet Lay-Up Repairs

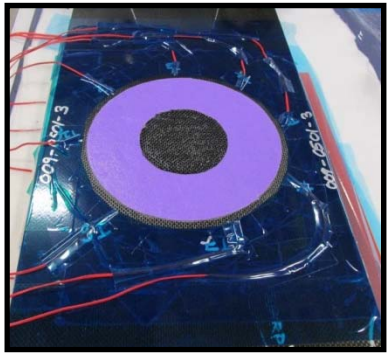


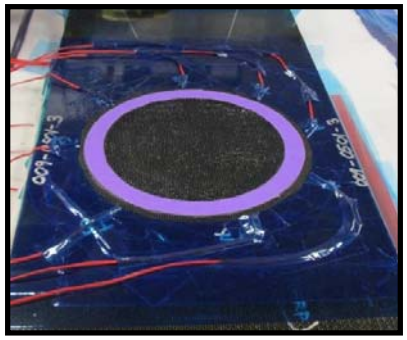
Scarfed panel ready for repair

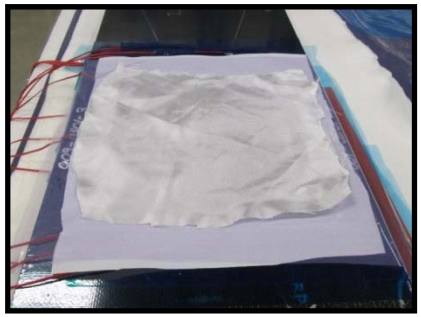


Wet Lay-up Fabric Impregnation

Wet lay-up Repair ply application

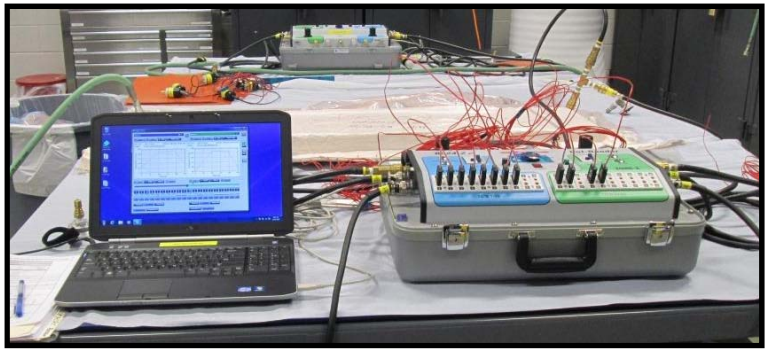






Wet lay-up repair bagging

Heat Blanket Application



Repair panel cure

CACRC Depot Repairs – Technicians' Experience

Mechanics	Company Certification/ Qualification Program	Years of Experience	Number of Repairs Performed	Rate of Rework
Mechanic 1	OJT, OEM fiberglass class Worked on metals initially	23 years working on AOG	~5000 repairs 60% wet lay-up, 40% prepreg repairs	Less than 10%
Mechanic 2	OJT, Operator basic course	Minimal	Undergoing Training	--
Mechanic 3	OJT, Operator basic course	16 years of experience with composites	~700 repairs 40% wet lay-up, 60% prepreg repairs	--
Mechanic 4	OJT, Operator Composite Classes	15 years of experience in composites	~1700 repairs 50% wet lay-up , 50% prepreg repairs	Less than 1% rework
Mechanic 5	OJT, 2 classes 1 week each Basic Composites I/II	3 years in composites	~500 repairs 60% wet lay-up, 40% prepreg repairs	--
Mechanic 6	OJT, Operator basic Composite Course (40 hours)/ Advanced Course (40 hours), OEM composite class (120 hours)	20 years of experience in composites	~4000 repairs 67% wet lay-up, 33% prepreg repairs	Less than 1% rework
Mechanic 7	OJT, operator general composites course (3 days) and advanced composites course (5 days)	24 years of experience in composites	~2500 repairs 10% wet lay-up, 90% prepreg repairs	Less than 5% rework
Mechanic 8	OJT, operator basic course 5 days, advanced course 5 days, Advanced Composites hands on course 1 week	13 years of experience in composites	~3500 repairs 50% wet lay-up, 50% prepreg repairs	Less than 5% rework
Mechanic 9	OJT	10 years in aircraft industry, 3.5 years of experience in composites early in career	~72 repairs Over 95% wet lay-up repairs	--

CACRC Depot Repairs – Technicians' Experience

Mechanics	Company Certification/ Qualification Program	Years of Experience	Number of Repairs Performed	Rate of Rework
Mechanic 10	OJT	2 years of experience in composites	~310 repairs Over 95% wet lay-up repairs	Minimal
Mechanic 11	OJT	3 years of experience in composites	~780 repairs	Less than 10% rework
Mechanic 12	OJT	20 years of experience in aviation, 10 years of experience in composites	~2000 repairs	Less than 5% rework
Mechanic 13	OJT	24 years of experience in aviation , 15 years of experience in composites	~1800 repairs: 45% wet lay-up, 55% prepreg repairs	Less or equal 2%
Mechanic 14	OJT	22 years of experience in aviation , 7 years of experience in composites		Less or equal 2%
Mechanic 15	OJT, operator 1 week course 2 week composite tooling course	18 years of experience in composites	~3000 repairs: 60% wet lay-up, 40% prepreg repairs	Less or equal 2%
Mechanic 16	OJT, operator 2 week course OEM basic repair course	27 years of experience in aviation , 14 years of experience in composites	~1100 repairs:	Less or equal 2%

Technicians′ Experience/ Perspective

Experience

- 75% of all mechanics had an airframe or an A& P license
- Varying levels of experience and competency

Technicians' Perspective

- Need more accessibility to engineering documentation and data
- Need training with OEM documents and SRMs, training to particular repair manual (differences between aircraft to aircraft)
- No one standard structural repair manual ("2 years to get familiar with one SRM")
- Need for standardized SRMs and for material standardization (more robust processes, improved efficiency "5 days spent gathering repair information and tooling/ 5 hours to complete the repairs")
- Importance of training for a better understanding of the repair process thus yielding more effective repairs and minimizing rework

Observations and Important Considerations

- CACRC standards cannot be used as a sole document without an SRM, can be used along with an SRM
- Best practices/ techniques for repair
- Part specific document required (Ideally a part specific SRM)
- Difficulties interpreting the standards (wet lay-up repair standard, mixing ratios in ARP 5256), missing or incomplete information as well as outdated nomenclature (mushroom sanding disk holder)
- Perspective on OEM versus Airline Depot/ MRO: many repairs are performed on similar parts at an OEM, whereas at an airline depot a mechanic may only repair a given part occasionally (practice/training needed on the same part)
- Constraints to perform the repair within a limited timeframe (AOG), Continuity between shifts

Observations and Important Considerations

Recommended Topics to be included in training:

- Working on example parts, history of composites.
- Composite part identification (know what to look for, material type, style…)
- Computer training for lead mechanics (access SRMs, find required documentation)
- Understand the differences between wet lay-up and prepreg repairs (cure temperature and outcome on structure, performance of wet lay-up and prepreg resins)
- Show examples of bad processes and the consequences, pass-fail criteria (Inadequate drying of a part, consequences of using wrong materials/ bad material replacement)

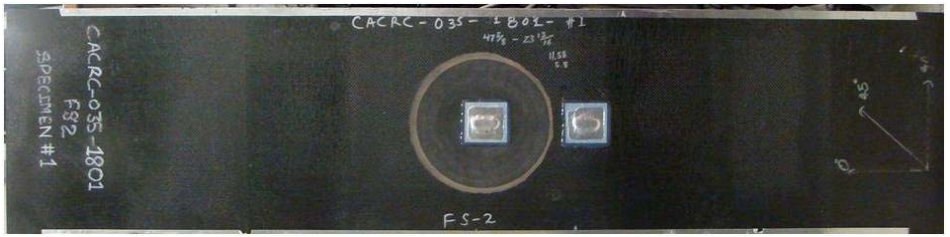
IMPLICATIONS ON SAFETY

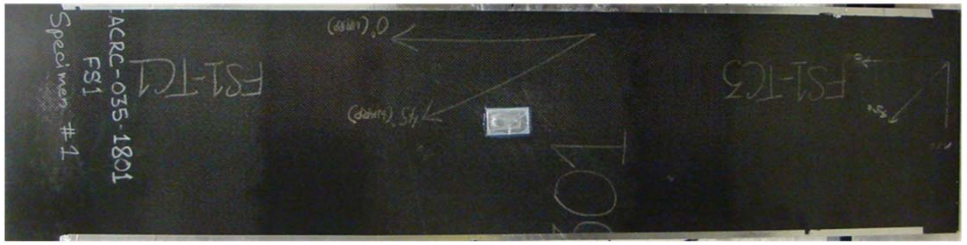
- Inspection required for critical steps, inspection points, process verification coupons

Need for **C**omposite **R**epair **T**echnician **T**raining and **C**ertification & **P**eriodic **C**ertification **V**alidation

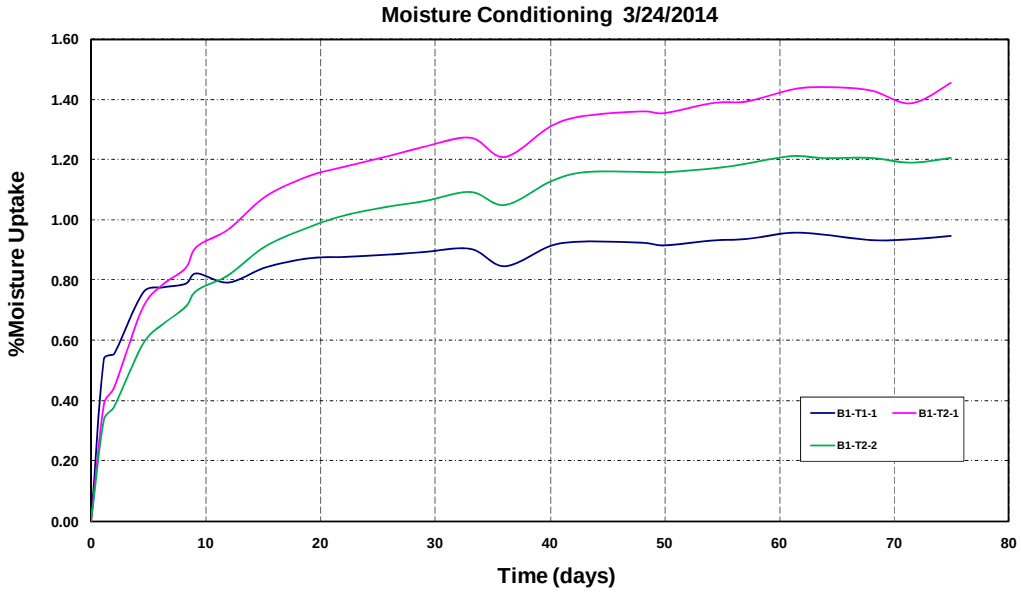
Research Status

- 90% of all repairs are complete (except the OEM prepreg repairs)
- Environmental Conditioning in progress
- Test Set-Up and Preparation in progress
- First tests to be conducted within a month





Specimen Instrumentation



Environmental Conditioning

Looking Forward

- Provide an assessment of the existing CACRC standards and identify areas of improvement

  Objective: Robust/Validated CACRC repair procedures/techniques standardized across different OEMs, airlines and repair stations
- Provide recommendations pertaining to repair training, materials and standards to improve structural integrity of repaired composite components (robust infrastructure for maintenance and supportability)
- Provide a measure of the structural integrity (static strength and residual strength after fatigue) of field repairs as compared to the OEM baseline repairs

Need for **C**omposite **R**epair **T**echnician **T**raining and **C**ertification & **P**eriodic **C**ertification **V**alidation

Questions and comments are encouraged

Thank you