JOINT ADVANCED MATERIALS & STRUCTURES
CENTER OF EXCELLENCE

CACRC Depot Bonded Repair Round Robin Investigation

Presented by:

Lamia Salah
March 31st, 2015

JAMS 2015 Technical Review

CACRC Depot Bonded Repair Investigation

- **Principal Investigators & Researchers**
  John Tomblin Ph.D., Lamia Salah Ph.D.
  Chathuranga Kuruppuarachchige, Ruchira Walimunige
- **FAA Technical Monitors**
  Curtis Davies, Lynn Pham
- **Other FAA Personnel**
  Larry Ilcewicz Ph.D.
- **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 – Suranga Nagendra
  Aviation Technology Associates – Marc Felice
  Hexcel – Justin Hamilton

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

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**

CECAM

JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

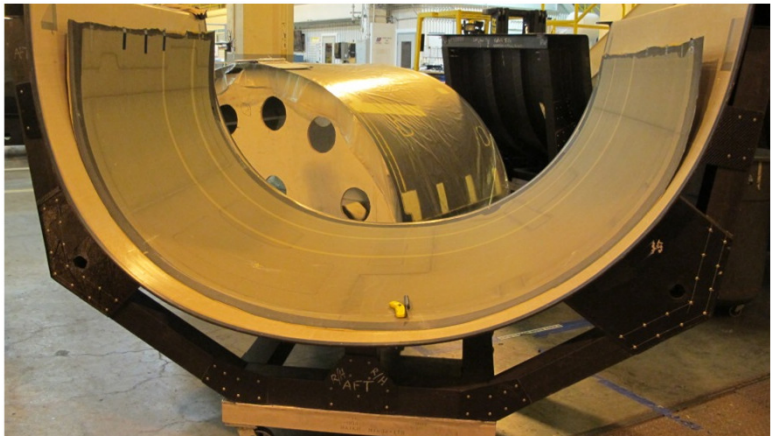
Introduction – In Service Experience

Lessons Learned:

- Outstanding performance where reliable processes were used
- Several in-service failures traced to 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)

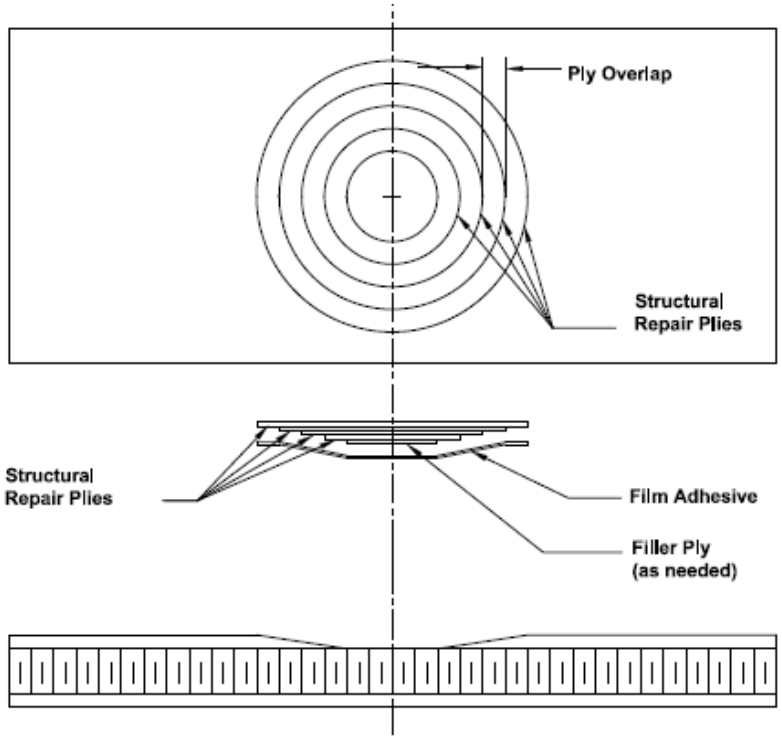
- NDI methods cannot guarantee absolute bond integrity Rigorous bond quality management, repair definition and process execution is essential to achieve repeatable and structurally reliable bonded repairs.



Complete Overhaul of a Composite Fan Cowl

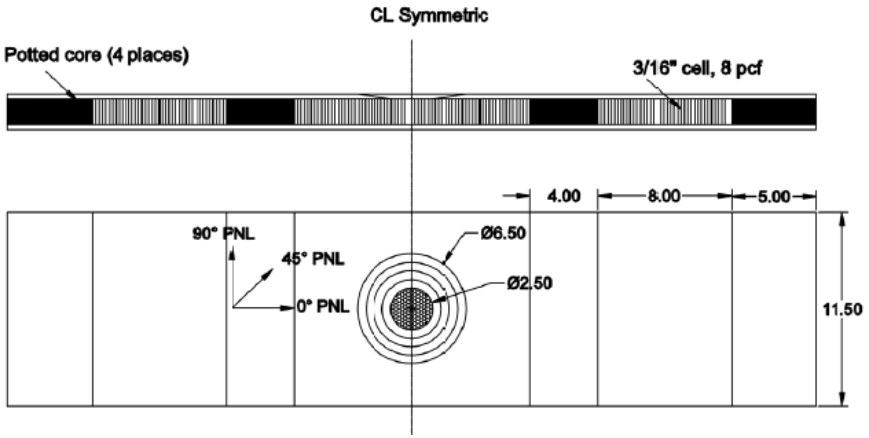
Research Objectives

- Evaluate the existing CACRC standards and approved materials used for repair of composite structures
- Assess the repair process variability between depots, using the same repair document procedures (similar to industry standard repair manuals) using CACRC repair techniques and materials provided to all the depots
- Investigate the variability associated with technician training (minimal level of experience versus extensive experience) on the performance of the repair
- 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 scarfed panels
- Evaluate the environmental effects on the static and residual strength after fatigue of these repairs

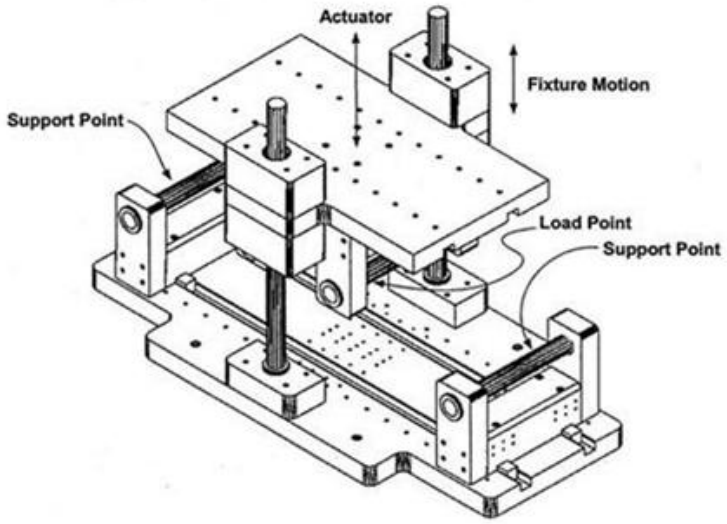


Schematic of a Bonded Repair to a sandwich panel (no core restoration, facesheet repair only)

Research Approach/ Methodology



Sandwich CACRC Prepreg Repair Configuration



Four-Point Flexure Fixture

Sandwich Repair Element Configuration
Representative of production hardware/ 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
- No core restoration, facesheet repair only (FS2)

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): G904 D1070 TCT 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): T300 fabric with EA9396 C2 laminating resin and EA9696 adhesive

CECAM

JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Test Matrix

Repair Station	Element 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	Unrepaired /2.5" hole/Scarf	N/A	Compression			3	
OEM	Repair/ 2.5" hole/ 0.25" scarf overlap	OEM-R1	Compression	M2		3	3
OEM	Repair/ 2.5" hole/ 0.5" scarf overlap	OEM-R1	Compression	M2		2	
NIAR	Repair/ 2.5" hole/ 0.5" scarf overlap	OEM-R2	Compression	M2		3	3
NIAR	Repair/ 2.5" hole/ 0.5" scarf overlap	OEM-R2	Tension	M2		3	3
NIAR	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M2		3	3
NIAR	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Tension	M2		3	3
NIAR	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M2		3	3
NIAR	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Tension	M2		3	3
Field Station 1	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M1		3	
Field Station 1	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M1		3	
Field Station 1	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M2		3	
Field Station 1	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M2		3	
Field Station 2	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M1		3	
Field Station 2	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M1		3	
Field Station 2	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M2		3	
Field Station 2	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M2		3	
Field Station 3	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M1		3	
Field Station 3	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M1		3	
Field Station 3	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M2		3	
Field Station 3	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M2		3	
Field Station 4	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M1		3	
Field Station 4	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M1		3	
Field Station 4	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M2		3	
Field Station 4	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M2		3	
Field Station 5	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M1		3	
Field Station 5	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M1		3	
Field Station 5	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R1	Compression	M2		3	
Field Station 5	Repair/ 2.5" hole/ 0.5" scarf overlap	CACRC-R2	Compression	M2		3	

116

OEM-R1	T300/934 w FM377 adhesive	CACRC- R1	M20PW with EA9695 adhesive
OEM-R2	EA 9396 C2 wet lay-up w EA9696	CACRC- R2	Epocast 52A/B wet lay-up
M1	Minimal level of Experience	RTA	Room Temperature Ambient
M2	Experienced Mechanic	ETW	Elevated Temperature (180°F) Wet

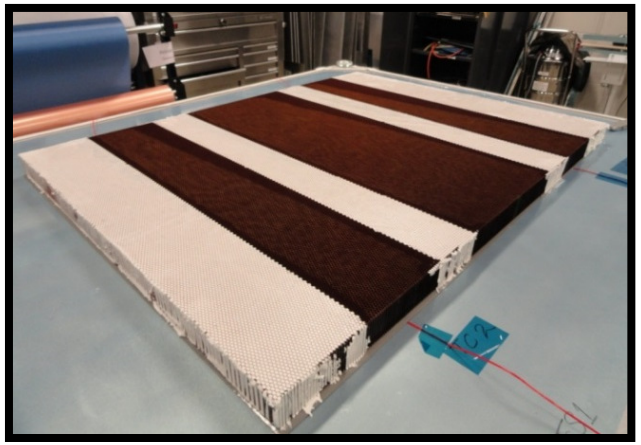
Research Methodology – Parent Panel Manufacture Assembly I

- Parent materials provided by the OEM
- Panel manufacture conducted at NIAR/NCAT using OEM approved processes verified by OEM quality assurance inspectors (40 large panels)
- Assembly 1 (uncured facesheet1 (FS1) and potted core) co-cured at 350°F for 120 minutes at 45 psi

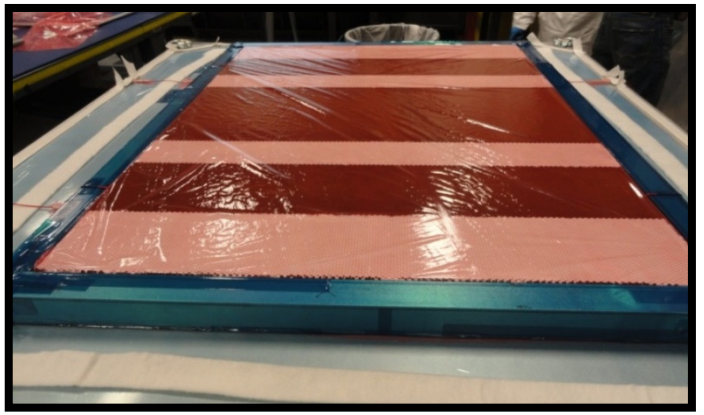
Facesheet 1 (FS1) lay-up

Film Adhesive Application

Corfil Application



Core Application onto facesheet 1 (FS1)



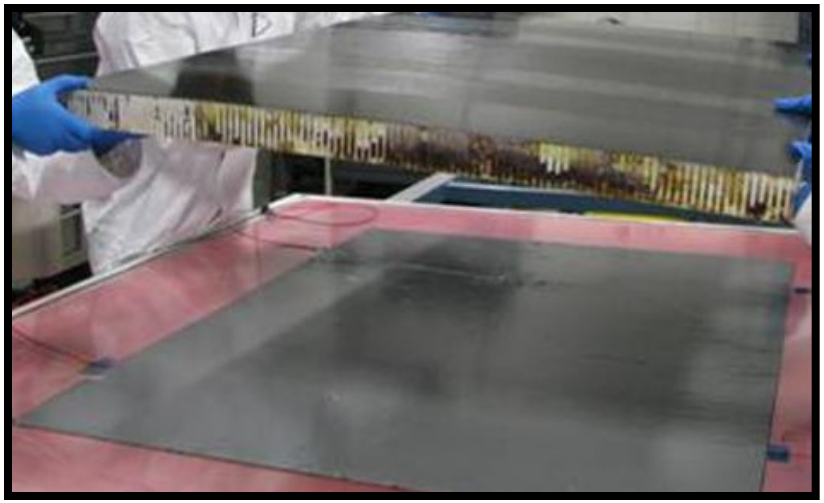
Assembly 1 Bagging and preparation for cure

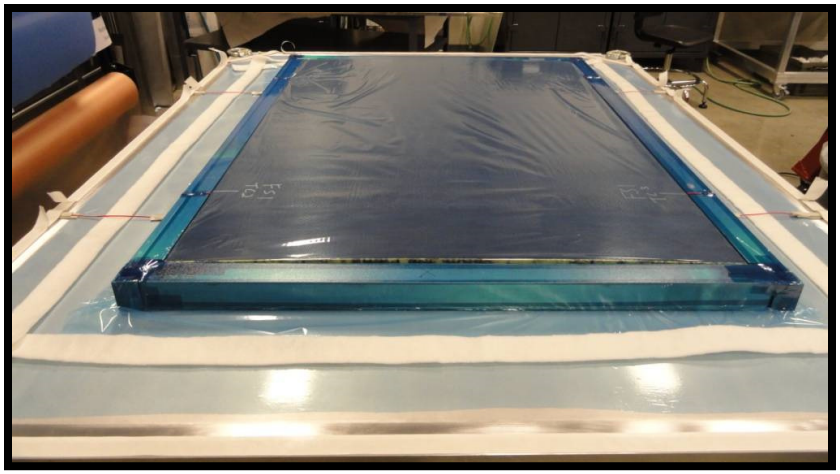
CECAM

JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

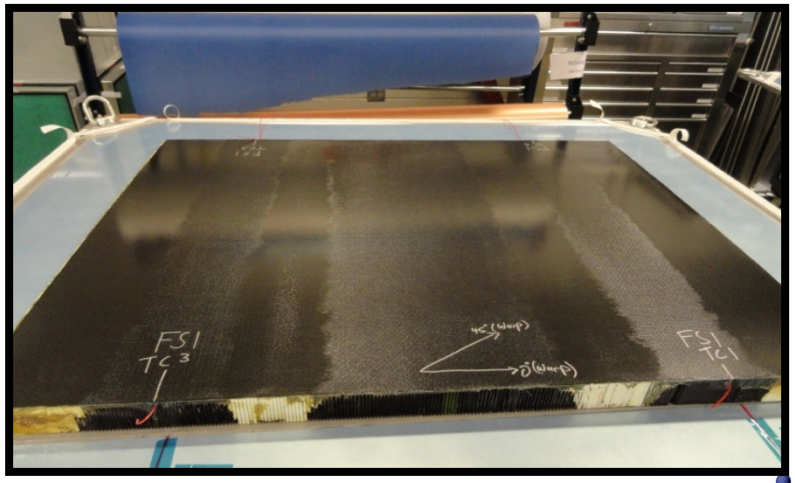
A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

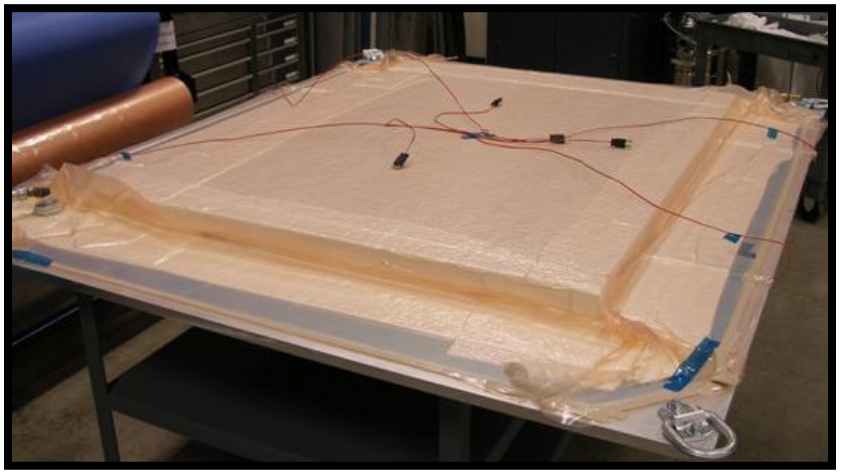
Research Methodology – Parent Panel Manufacture Assembly II





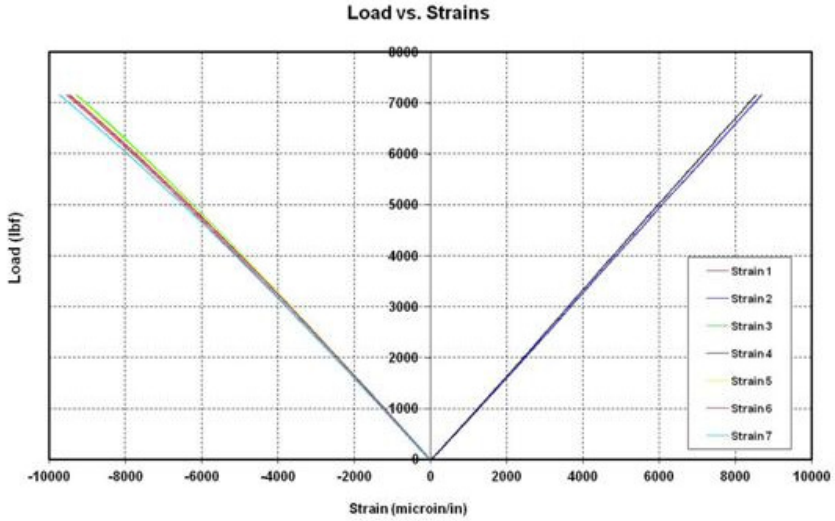
Uncured Assembly 2 (facesheet 2 and adhesive) co-bonded to cured assembly 1



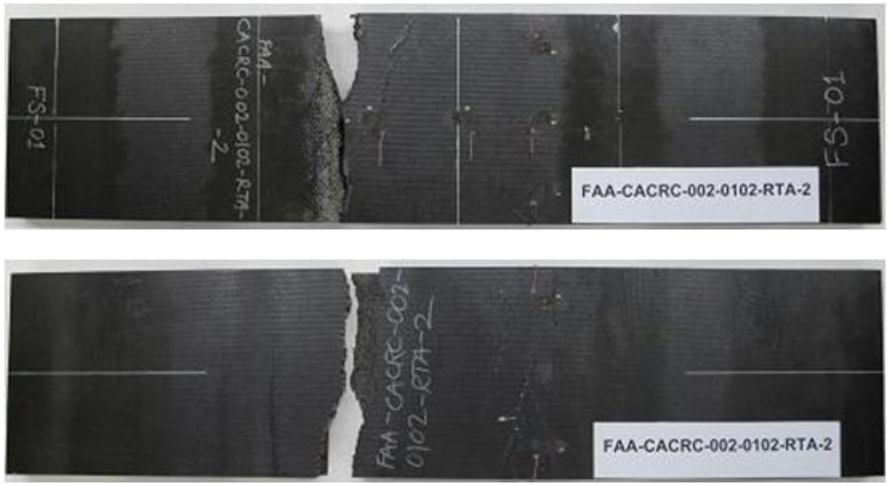


Assembly Bagging in preparation for cure

Research Methodology – Sandwich Element Design Validation

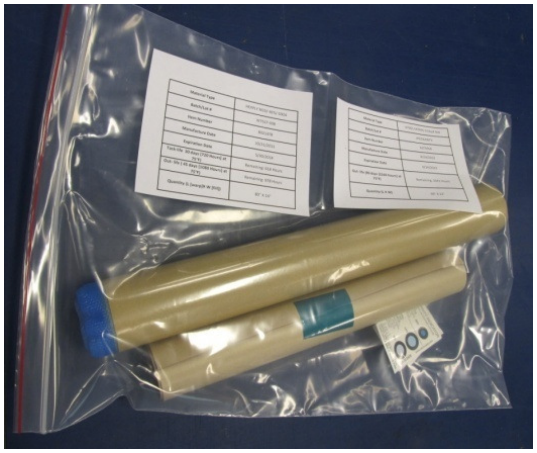


- 3 undamaged-pristine beams were tested to establish the undamaged parent element capability at RTA
- Good correlation between experimental results and predictions
- Average failure strains (-9335με -compression and 8492με -tension)

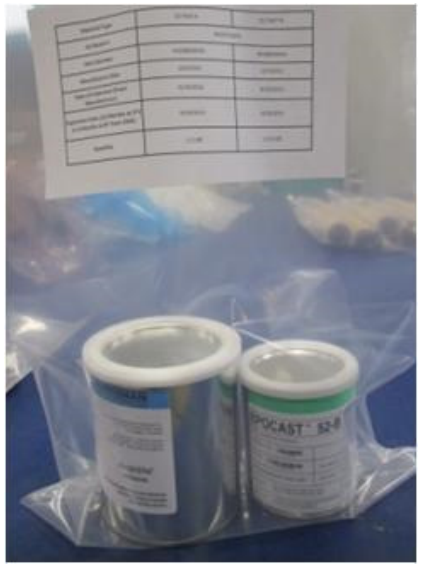


Typical Failure Modes – Undamaged beams

Repair Procedure and Kit preparation



CACRC Prepreg Kit



CACRC Wet Lay-Up Resin

- A detailed Repair Document procedure (similar to industry standard repair manuals) 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)

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
- Huntsman Epocast 52A/B resin
- Peel ply and perforated film for wet lay-up bagging

<u>Notes:</u>

- Difficulties in material procurement, long lead times and difficulty obtaining small quantities
- CACRC Materials not commonly called out today in composite repairs

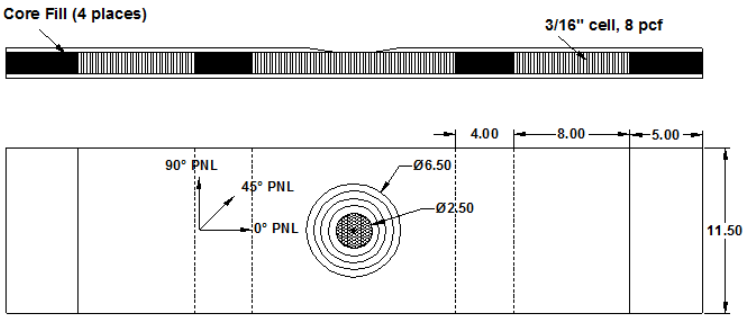
CECAM

JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

Repair Checklist Inspection Points and Instructions (Prepreg Repairs)

- Drawing of part showing location of damage and scarf inner and outer boundaries
- Repair Station Environment
  date, time, temp, RH at the start and end of the repair
- Repair kit information
  material type, date of shipment, batch/roll, manufacture date
  expiration date, original out life, remaining out life
- Instructions for thawing repair kit/ information on storage life and out time
- Repair kit information, prepreg and adhesive ply dimensions
- Instructions for Repair Material Inspection
- Panel marking, orientation, repair location (FS2)- Repair conducted on co-bonded facesheet 2
- Panel masking (ARP 4916)
- Scarf sanding instructions (AIR5367) – Inspection
- Scarf cleaning instructions (ARP4916) – Inspection
- Core Depth measurement/ filler ply requirement – Inspection
- Water Break Test (ARP4916)
- Panel Drying instructions prior to repair (ARP4977)
- Final Clean instructions (ARP4916) – Repair must be conducted within 20-30 min after final cleaning
  no particular cleaning agent was specified



Repair Panel Marking

(scarf inner diameter 2.5", outer diameter 6.5")

Repair Checklist Inspection Points and Instructions (Prepreg Repairs)

- Repair lay-up instructions – Inspection
- Thermocouple installation (8 thermocouples, ARP5144) and bagging instructions (no bleed, ARP 5143), leak check – Inspection
- Cure instructions (ARP5144), 2 heat blankets required

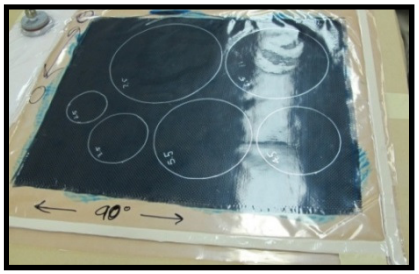
  Hot bonder calibration information – Inspection
- NDI using tap testing per ARP 5089

Cure Cycle - CACRC Prepreg Material				
Cure Parameters	**Units**	**Requirements**	**Units**	**Requirements**
Heating Rate	°C/min	1-3	°F/min	2-5
Cure Temperature	°C	120-130	°F	248-266
Cure Time	min	180-240	min	180-240
Cure Pressure	kpa	>0.75	in-Hg	>21
Cooling Rate	°C/min	5 max	°F/min	9

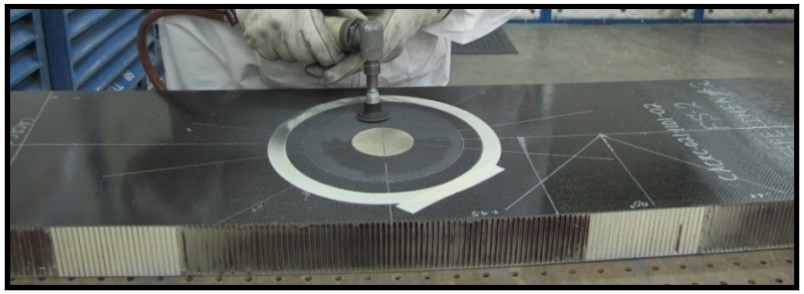
CACRC Repairs - Depot #1

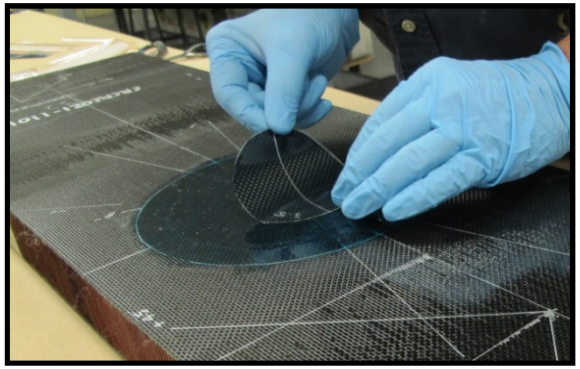
- Depot 1 performed repairs with CACRC materials (CACRC-R1 and CACRC-R2) only as defined in test matrix table

CACRC Repair Element Masking in Preparation for Scarf Sanding

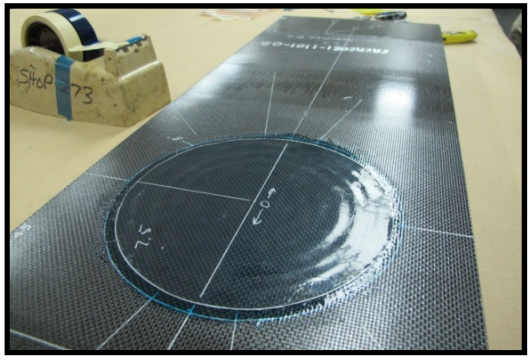


Wet lay-up resin impregnation





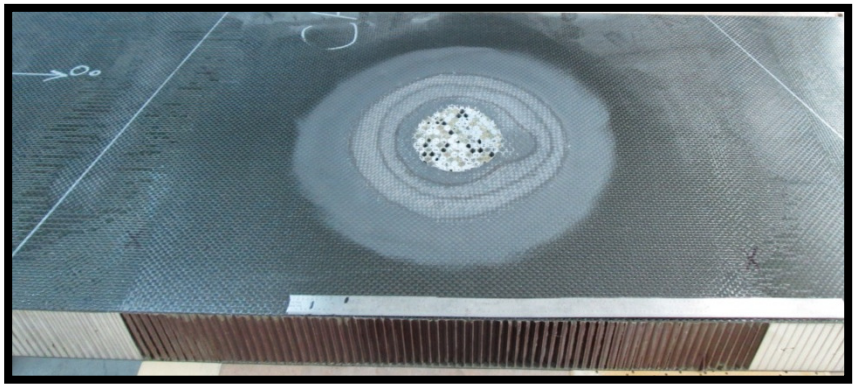
Scarf/Taper Sanding



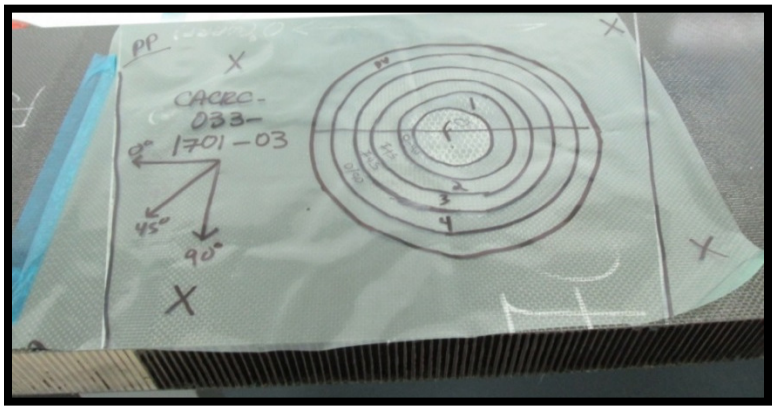
Wet lay-up repair ply application

CACRC Repairs - Depot #2

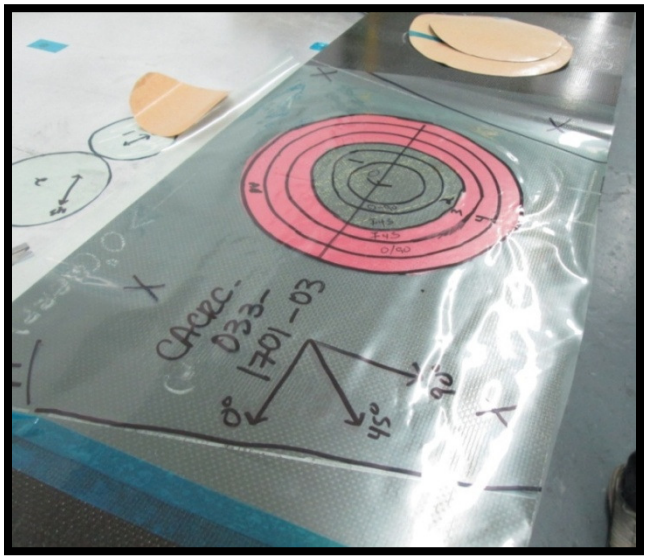
- Depot 2 performed repairs with CACRC materials (CACRC-R1 and CACRC-R2) only as defined in test matrix table



Element scarf sanded in preparation for repair



Repair Ply Template

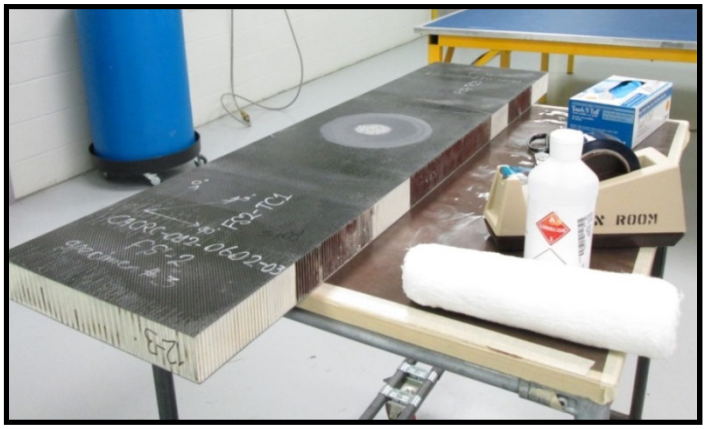


Repair Ply Application

Cured Repair

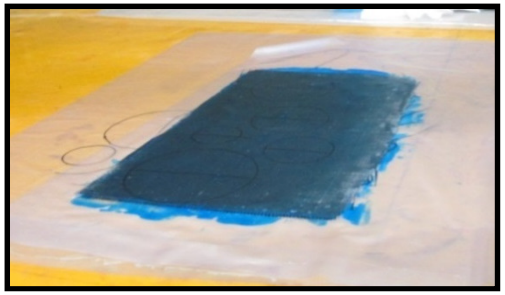
CACRC Repairs - Depot #3

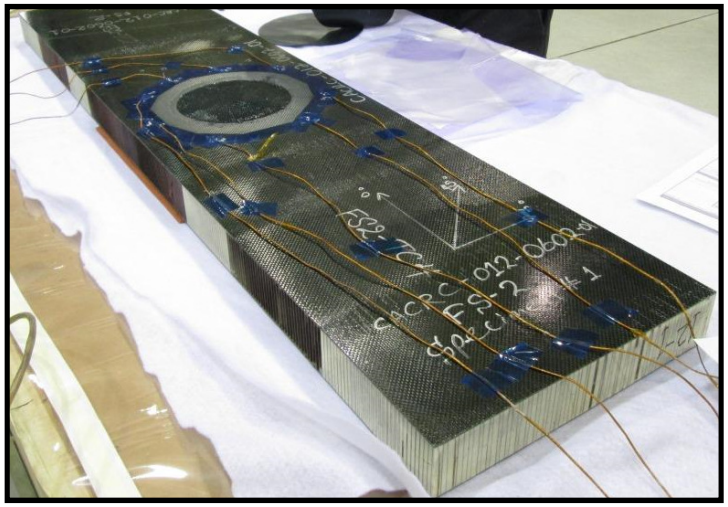
- Depot 3 performed repairs with CACRC materials (CACRC-R1 and CACRC-R2) only as defined in test matrix table



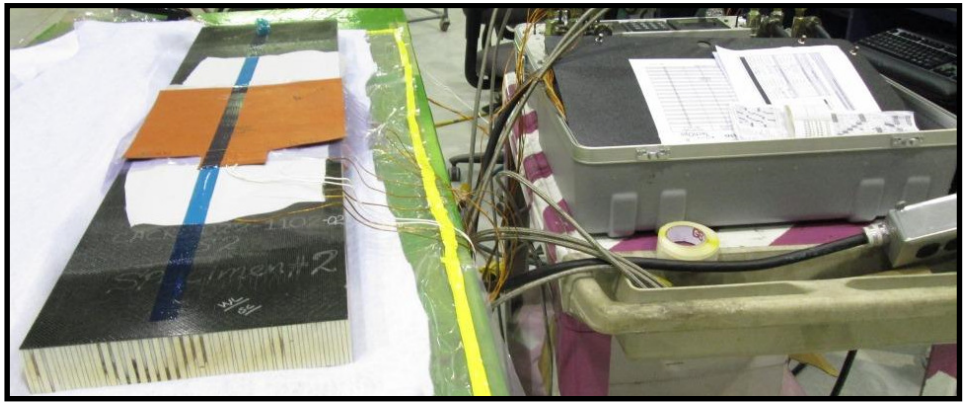
Element scarf sanded in preparation for repair

Wet lay-up resin impregnation



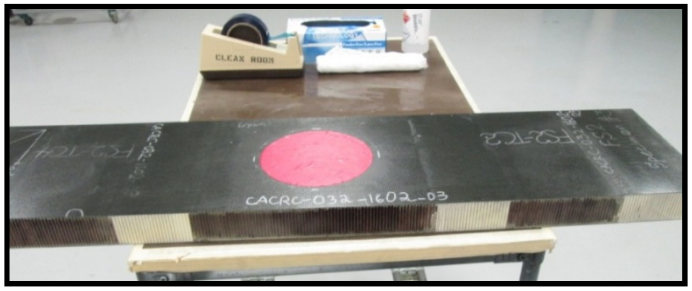


Wet lay-up repair application

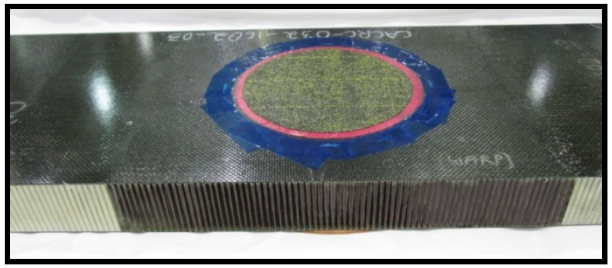


Repair Bagging in preparation for cure

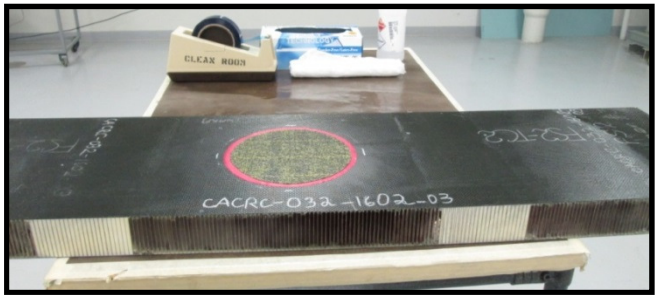
CACRC Repairs - Depot #3



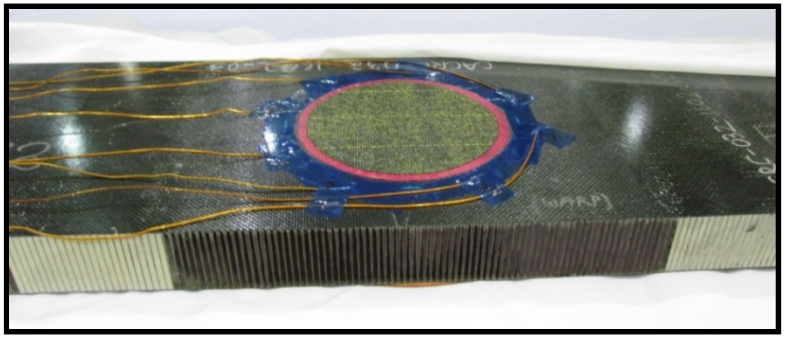
Adhesive application – prepreg repair



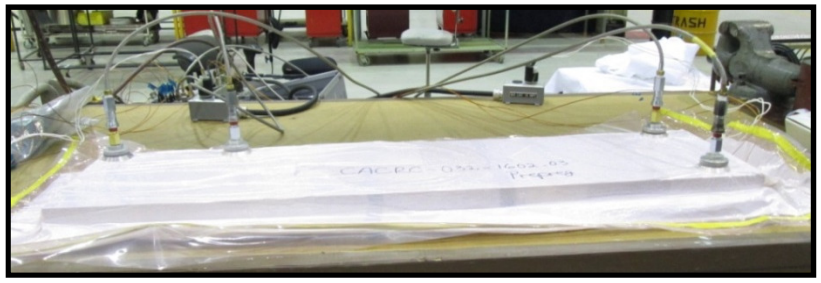
Repair Masking – prepreg repair



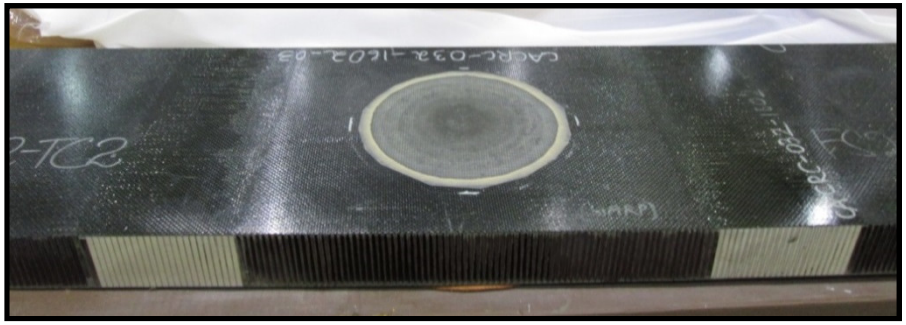
Repair application – prepreg repair



Thermocouple Application – prepreg repair



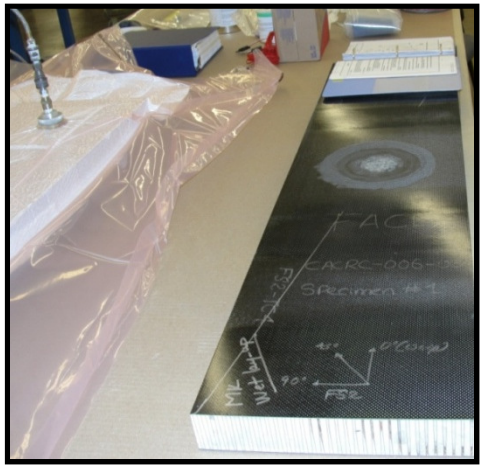
Repair Bagging



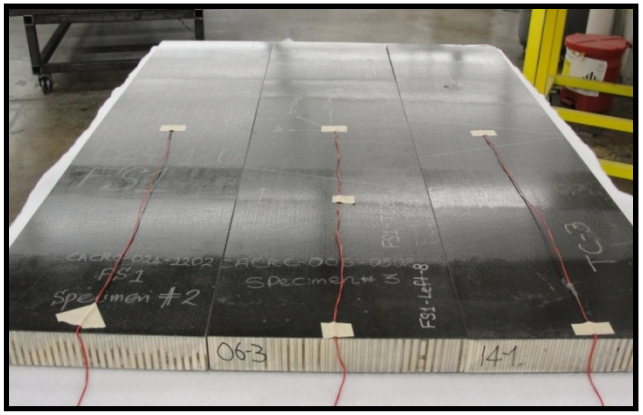
Cured repair

CACRC Repairs - Depot #4

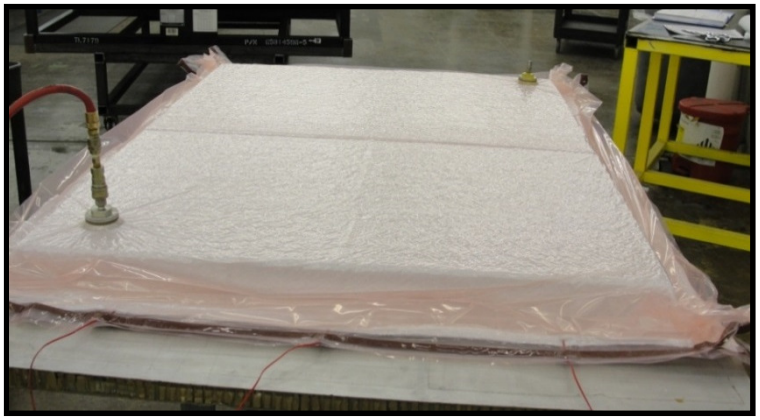
- Depot 4 performed repairs with CACRC materials (CACRC-R1 and CACRC-R2) only as defined in test matrix table



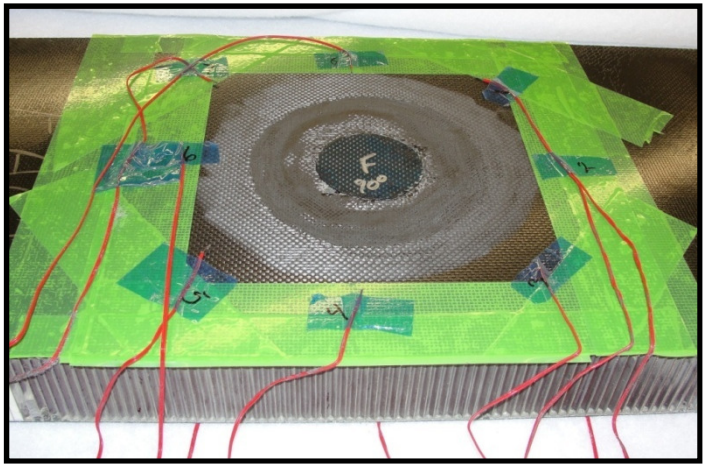
Repair Element Scarf Sanded in Preparation for Repair



Repair Elements Scarfed and prepared for Drying



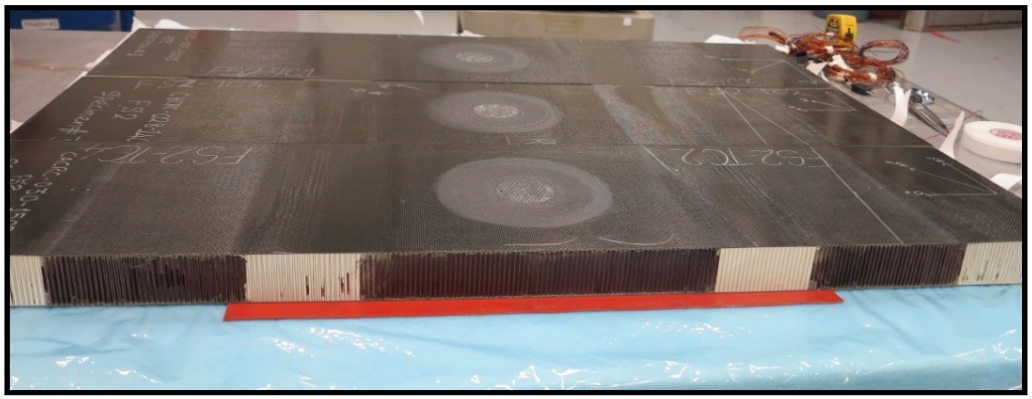
Repair Element Drying



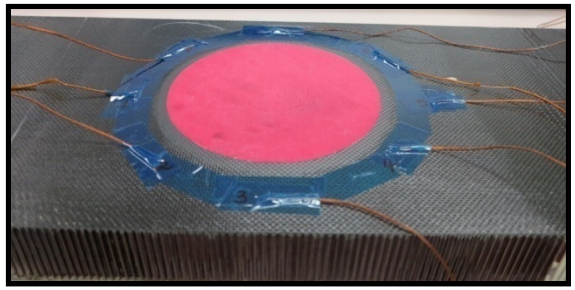
Repair Application

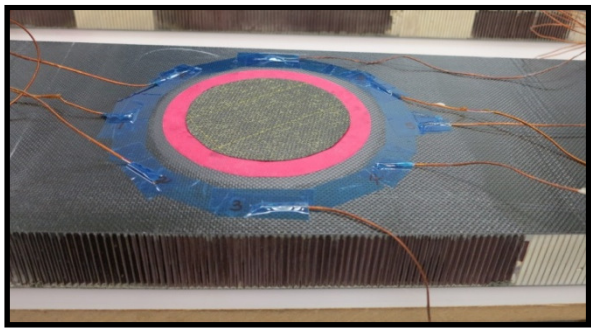
CACRC Repairs - Depot #5

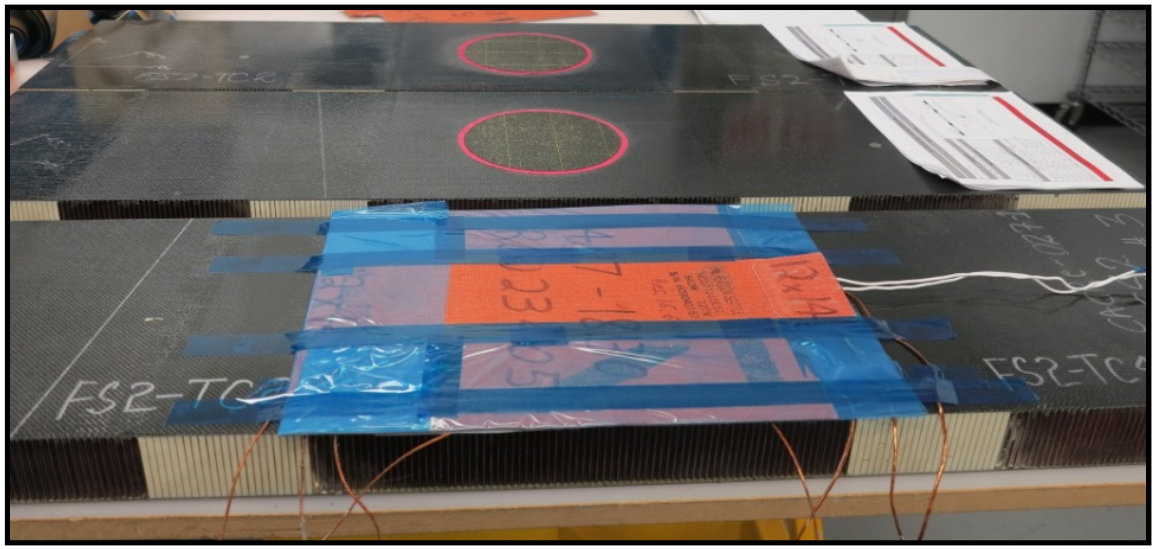
- Depot 5 performed repairs with CACRC materials (CACRC-R1 and CACRC-R2) only as defined in test matrix table



Scarfed Elements prepared for drying

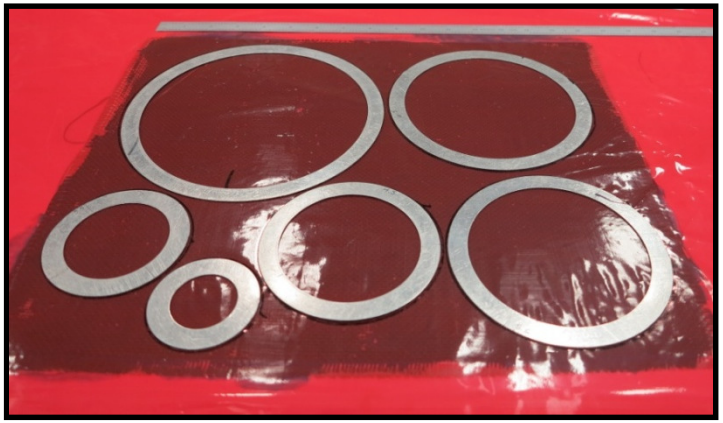




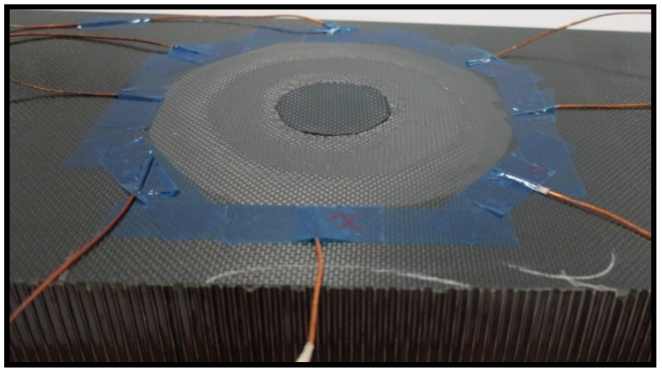


Prepreg Repair Application

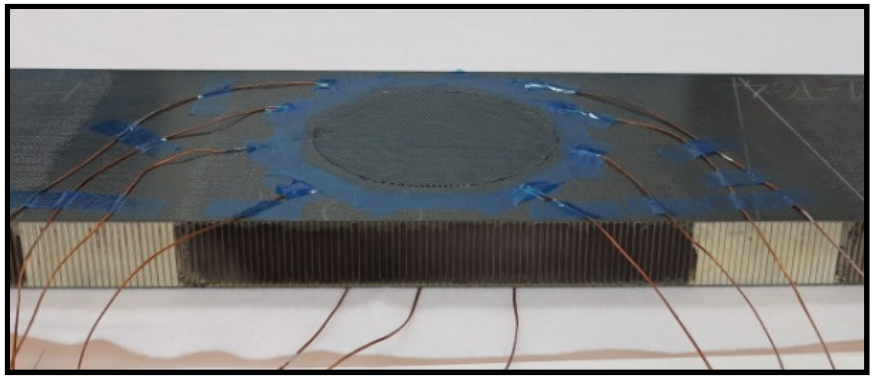
CACRC Repairs - Depot #5



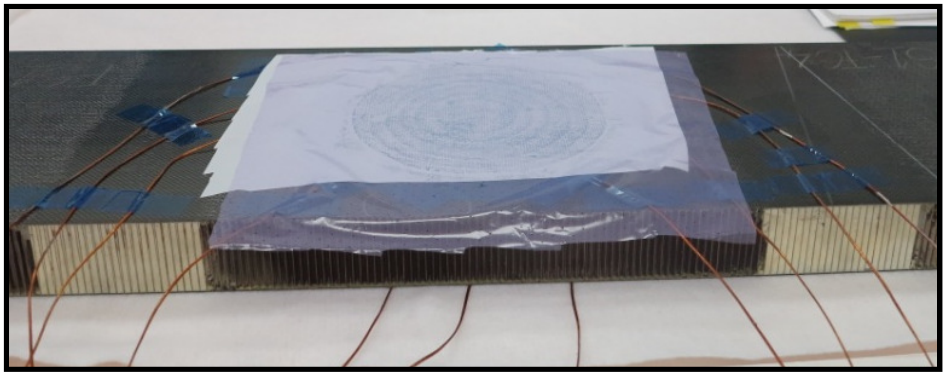
Wet lay-up ply impregnation



Wet lay-up repair application

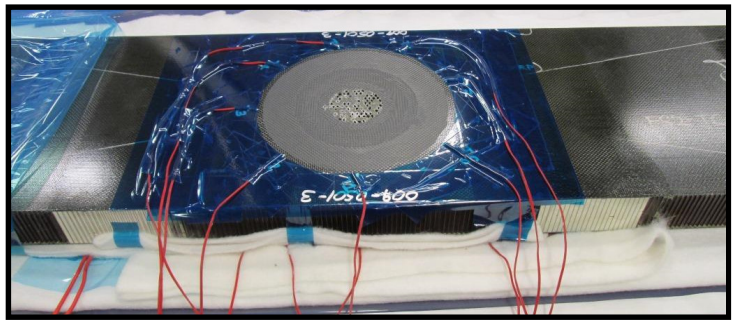


Wet lay-up repair application

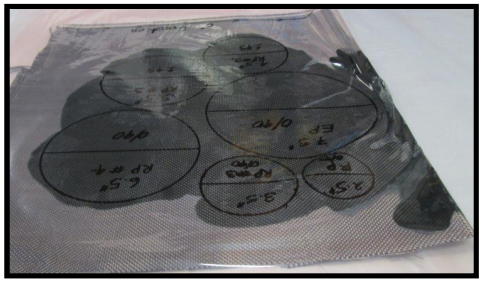


Wet lay-up repair bagging in preparation for cure

OEM-R2 Wet Lay-Up Repairs

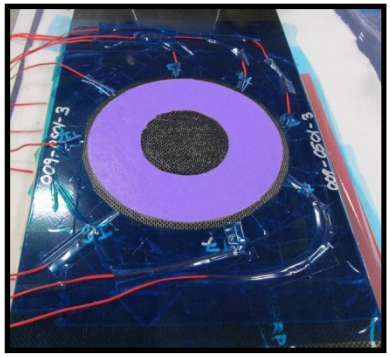


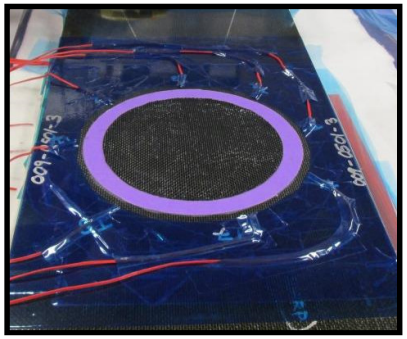
Scarfed panel ready for repair

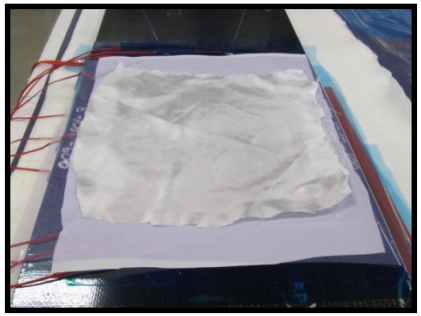


Wet Lay-up Fabric Impregnation

Wet lay-up
Repair ply
application

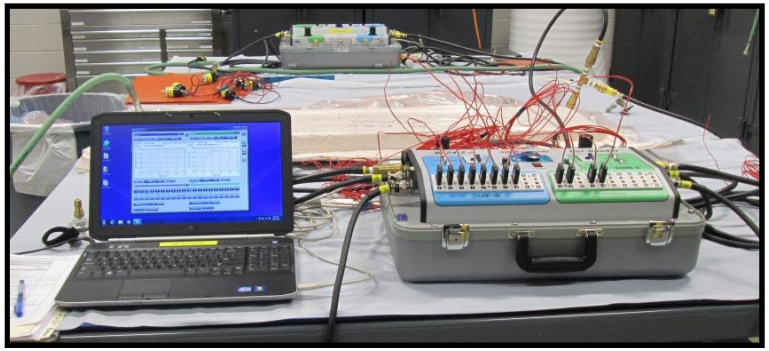






Wet lay-up
repair bagging

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	--

Data Self Reported by Mechanics

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 with composite materials and structures

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 and repeatable repairs and minimizing rework

Observations and Important Considerations

- CACRC standards cannot be used as a sole document without a detailed repair document, can be used along with an SRM
- Best practices/ techniques for repair (repair designer's responsibility to select which ones to use)
- 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 unfamiliar 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

Composite **R**epair **T**echnician **T**raining and **C**ertification &
Periodic **T**raining **V**alidation

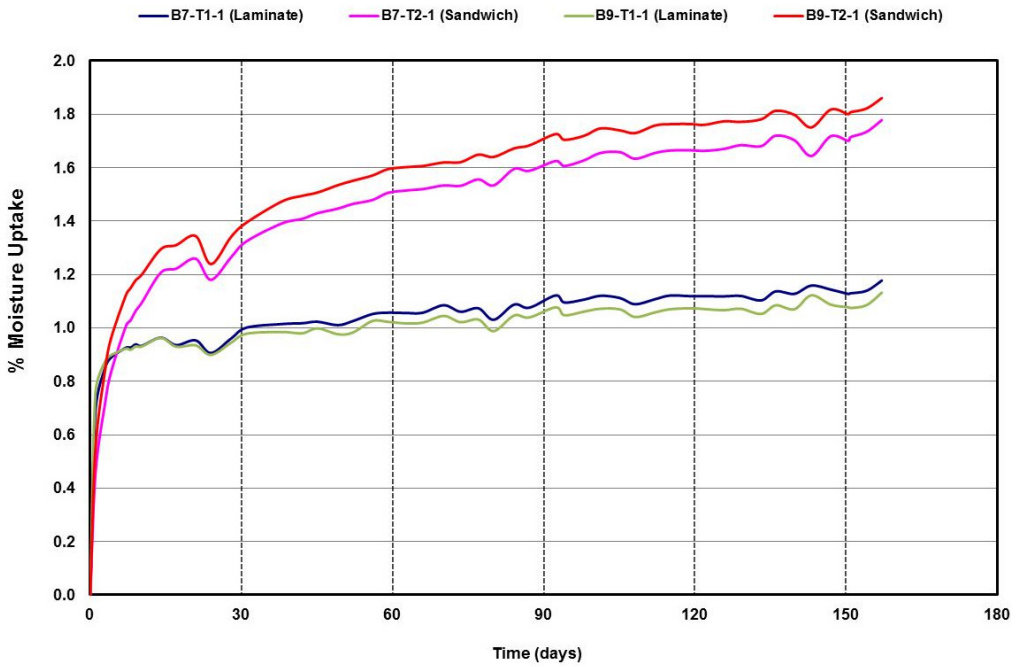
CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Research Status

- All repairs are 95% complete (one participant was not able to complete repairs, data not be included in study)
- Environmental Conditioning (145°F, 85%RH) in progress (last 8 OEM-R1 elements)
- Mechanical Testing, data reduction and review in progress (95% complete)
- All ETW fatigue specimens were cycled at a load equivalent to 2000με at 180°F and survived 165000 cycles (undamaged, CACRC R1 and R2 repairs and OEM R1 repairs)
- No difference between baseline and repair element static and residual strength after fatigue testing



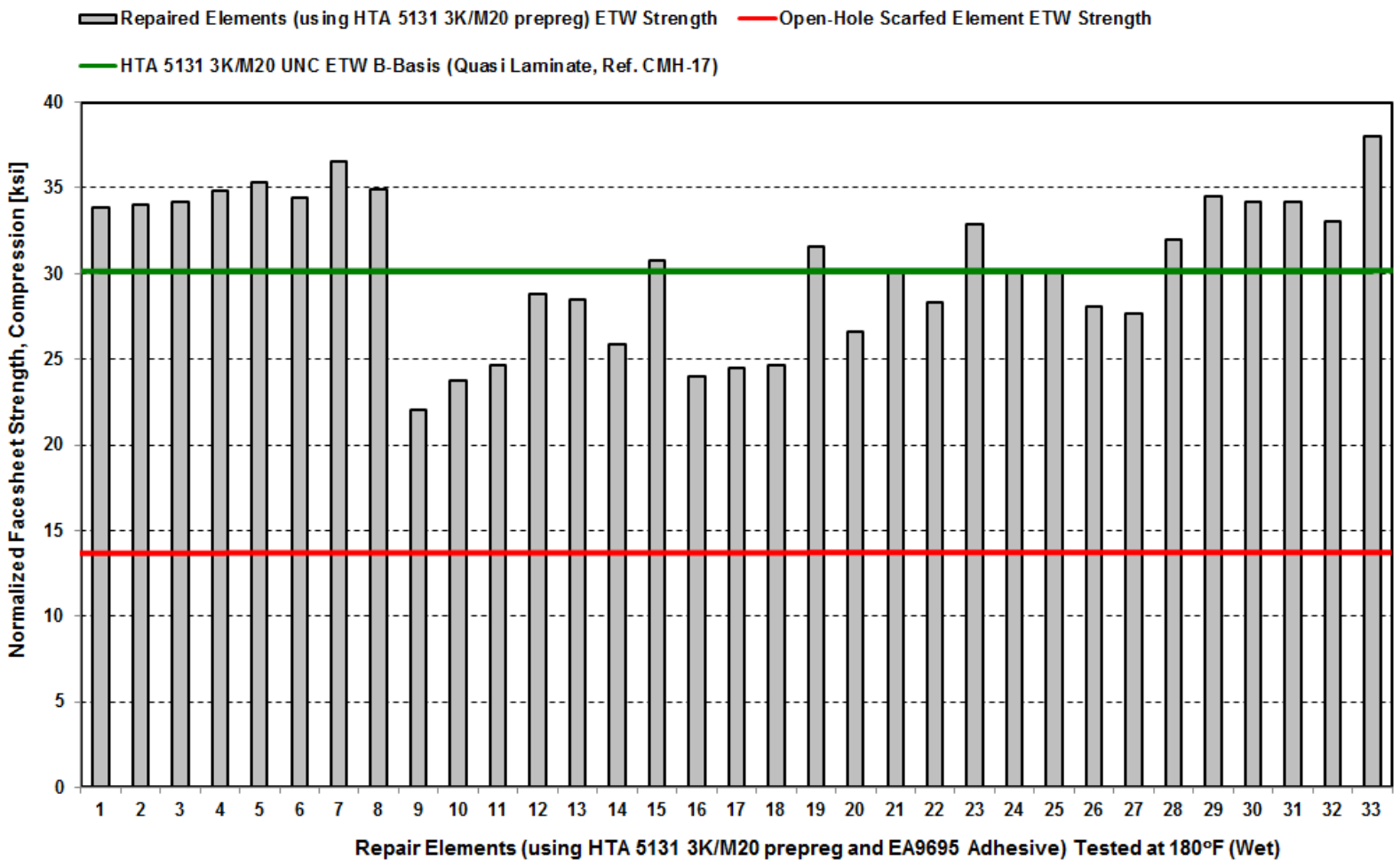
Representative Moisture Conditioning Chart
Laminate traveler total moisture content ~ 1.16%
Sandwich traveler total moisture content ~ 1.82%

CECAM

JAMS
JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE

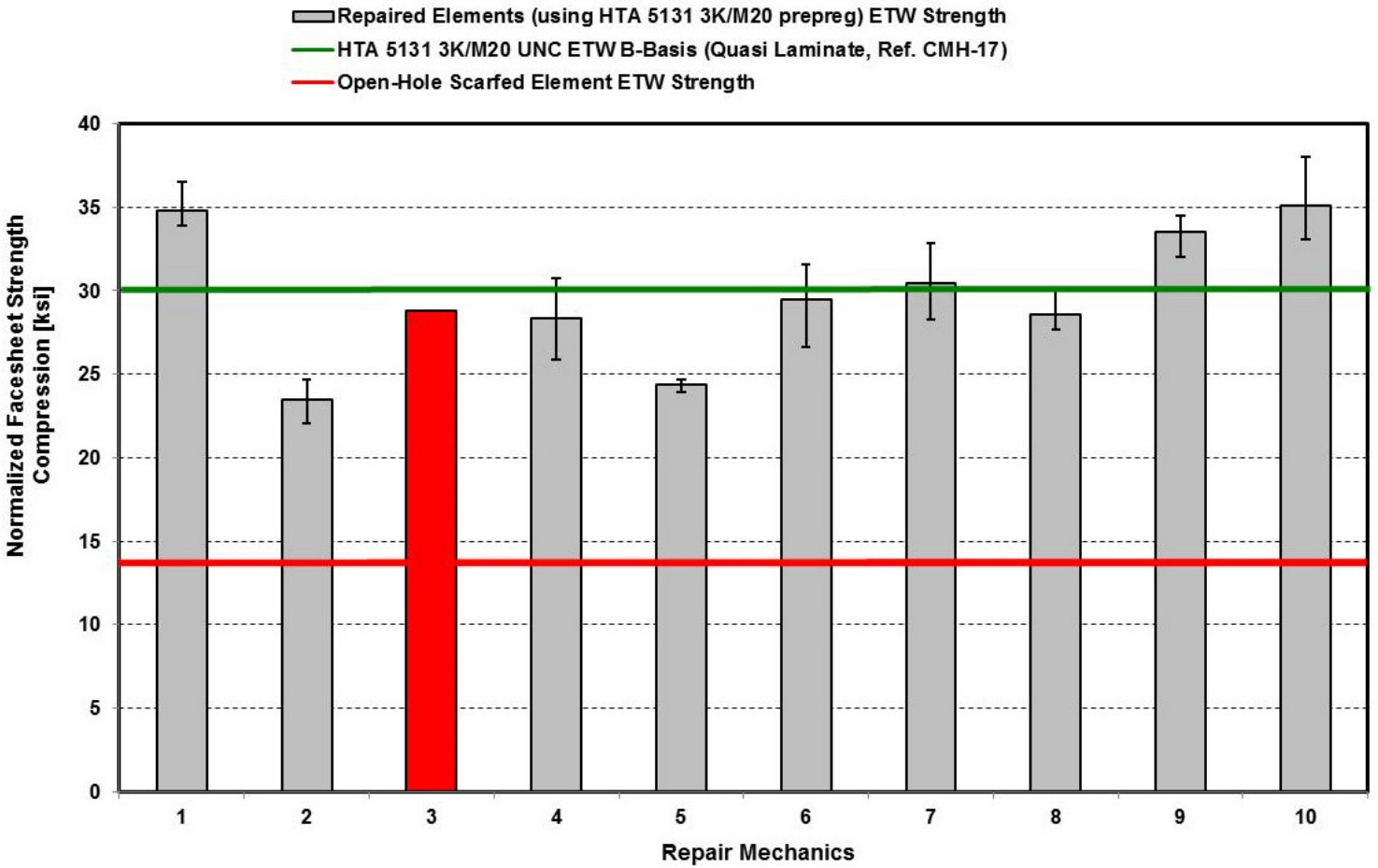
A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

Results – CACRC Prepreg Repairs using M20 PW/ EA9695



- 33 data points (instead of 39): 5 repairs not completed, 1 element damaged during testing
- Repair Element Average Strength: 30.5ksi Min=22.1ksi, Max=38.0 ksi, CPT=0.0083", COV 14.1%
- Undamaged Element Strength: 35.4ksi Min=32.9 ksi Unrepaired Open-Hole Scarf Strength:13.7 ksi
- M20 Laminate Compression QI OHC/UNC B-Basis Value (CMH-17)24 ksi/ 30.1 ksi

Results – CACRC Prepreg Repairs using M20 PW/ EA9695

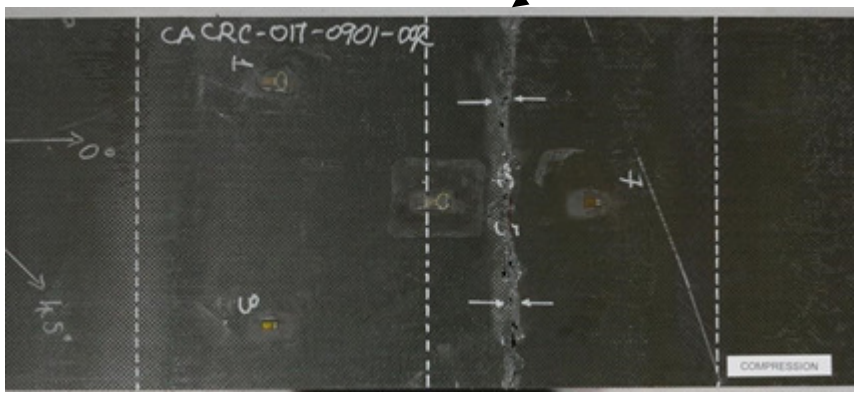


- Repair data (CACRC-R1), repair elements tested at 180°F (Wet)
- Participant#3 performed only one CACRC-R1 prepreg repair

Results – CACRC Prepreg Repairs – Representative Failure Modes

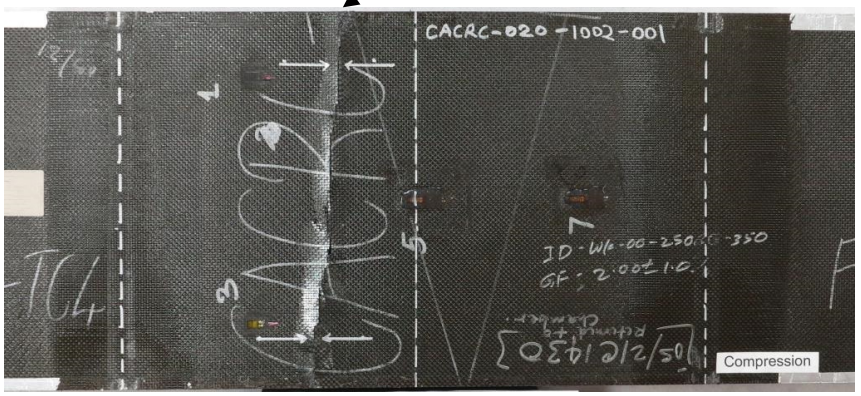
All baseline/ Undamaged Elements yielded facesheet compression failures in the gage section

Failure Location



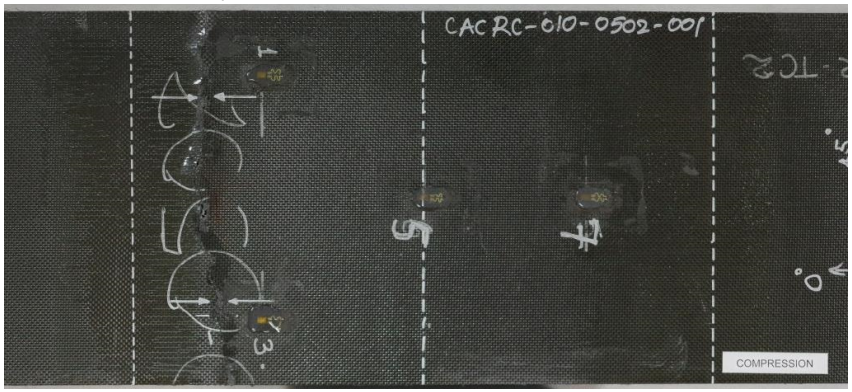
Gage Section

Failure Location



Gage Section

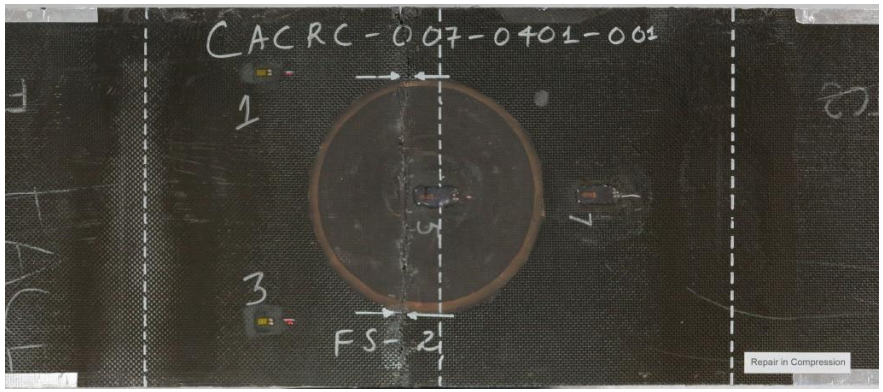
Failure Location

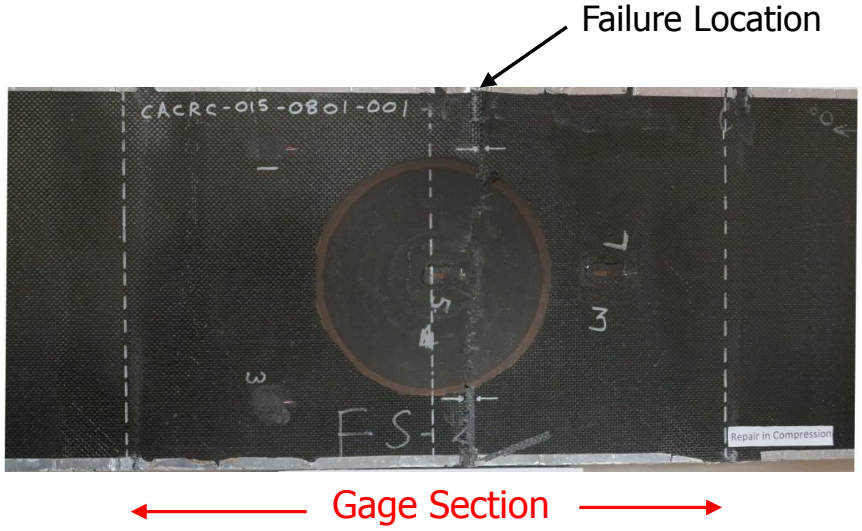


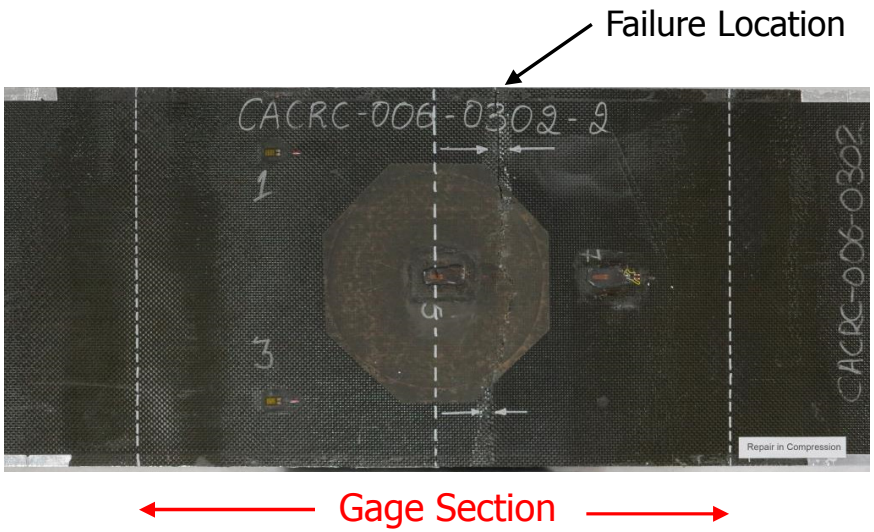
Gage Section

Results – CACRC Prepreg Repairs – Representative Failure Modes

All elements repaired with CACRC prepreg yielded laminate compression failures in the gage section (48% failed outside the repair, 52% failed within the repair)

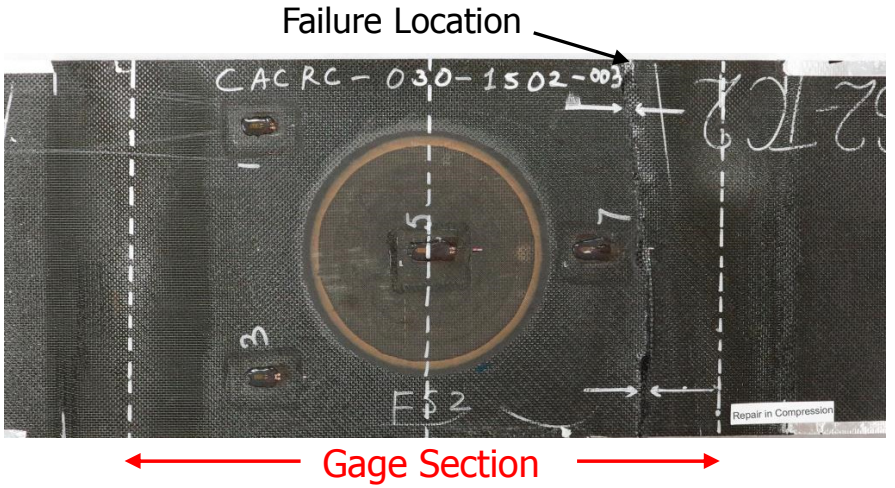


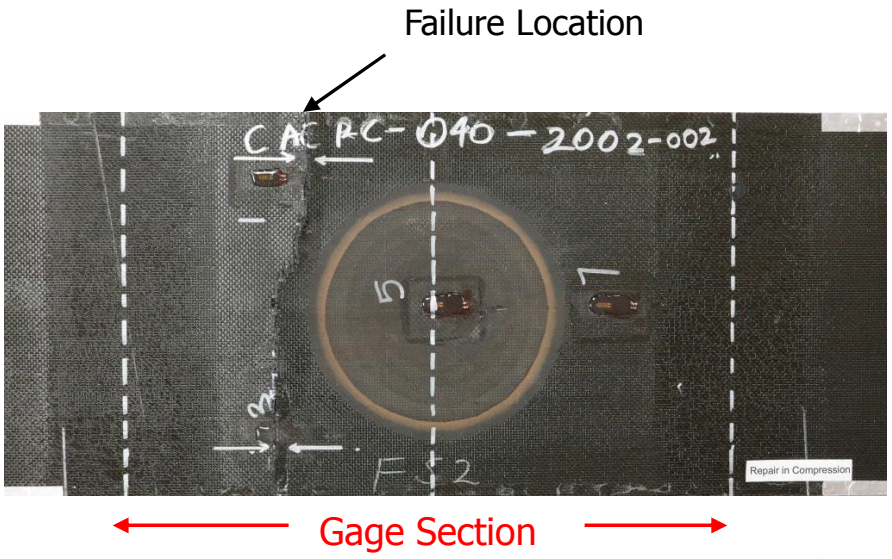


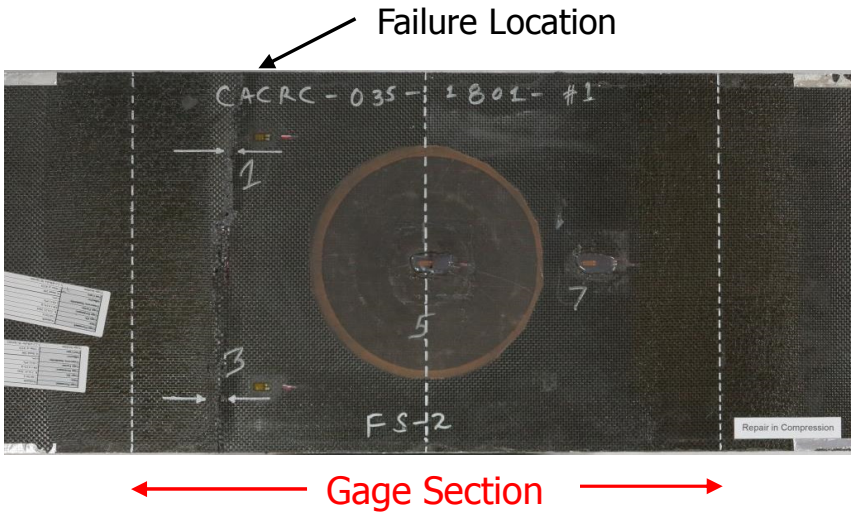


Preliminary Results – CACRC Prepreg Repairs – Representative Failure Modes

All elements repaired with CACRC prepreg yielded laminate compression failures in the gage section (48% failed outside the repair, 52% failed within the repair)







Prepreg Repair Checklist Preliminary Review and Findings

- Repair Timeframe (December 2012, February 2013, March 2013, June 2013, October 2013)
- Repair station environment – not documented in some cases, temperature exceeds 70°F
- Material within shelf life
- Material Out time, M20 prepreg (42 days AMS 3970)
- Material Out time, EA9695 adhesive (10 days AMS 3970)
- Material close to maximum out time in some cases (AMS 3970)
- Same batch of prepreg used, 2 adhesive batches used
- Time lag between drying and final cure:

Comments: "concerning repair station environment information, all 3 prepreg panels were prepared at the same time up to step 10. From that point on, steps 10-14 each panel was handled individually. Because of holidays vacation and local work demands for other products, these panels sat covered with solid release til scheduling allowed." "cure for spec 3 was cancelled 15 min after cure because I discovered that I did not put solid release in the lay-up"

- Bagging scheme (vertical bleed method was used for one set of prepreg repairs, instructions specify no bleed method)
- Ramp up rate varied between 3-5°F
- Soak time varied between 180-240
- Vacuum varied between 22-27in Hg

Looking Forward

- Provide an evaluation of the CACRC standards and recommendations for areas of improvement
- Provide recommendations pertaining to repair personnel training, materials and standards to improve structural integrity of repaired composite components
- Provide a measure of the structural integrity (static strength and residual strength after fatigue) of field repairs as compared to OEM repairs (performed by experienced OEM personnel in laboratory conditions)
- Identify key process parameters in the execution of bonded repairs of composite structures

Looking Forward

- Infrastructure for maintenance and supportability – robust repair design and execution will yield strong durable bonded repairs
- Composite repair personnel training, certification and periodic training re-validation
- Part specific training, taking into account learning curve (practice/ iterations with actual parts yielding consistent repairs)
- Detailed process checklists/ step by step instructions and repair records and documentation
- Further studies will be required to assess other factors