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CACRC Depot Bonded Repair Investigation – Round Robin Testing

2012 Technical Review

Presented by:
Lamia Salah
NIAR - WSU

CACRC Depot Bonded Repair Investigation

- Principal Investigators & Researchers

  Dr. John Tomblin, Lamia Salah
- FAA Technical Monitor

  Curtis Davies, Lynn Pham
- Other FAA Personnel Involved

  Larry Illcewicz
- Industry Participation

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

  Boeing – Russell Keller / Jeff Baucum

  Airbus – Francois Museux

  Delta/Northwest Airlines – Ray Kaiser

  United Airlines – Eric Chesmar

  Sandia National Laboratories – Dennis Roach, Stephen Neigdik

Motivation – Key Issues

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

Challenges Associated With the Use of Composites in Airframe Structures

Material Fabrication And Processes, Analysis Methods, Structural Health Monitoring, Lightning Strike Protection, Recycling, Repair Methods and Standardization

Important Considerations Associated with Bonded Repair of Composite structures

long term durability (fatigue endurance) of adhesively bonded repairs
Environmental resistance/ durability
Limitations in maintenance environment: Autoclave vs Out of autoclave systems
Repairability (dictated by the parent system, material mechanical capability, chemical compatibility)

References:
1-Chesmar, E., "Repair And Maintencance Implementation: Airline Experience, Problems, Concerns and Issues, Presented at FAA Bonded Workshop June 2004.

Motivation- Key Issues

Design Considerations – Composite Structures [1]

Durable

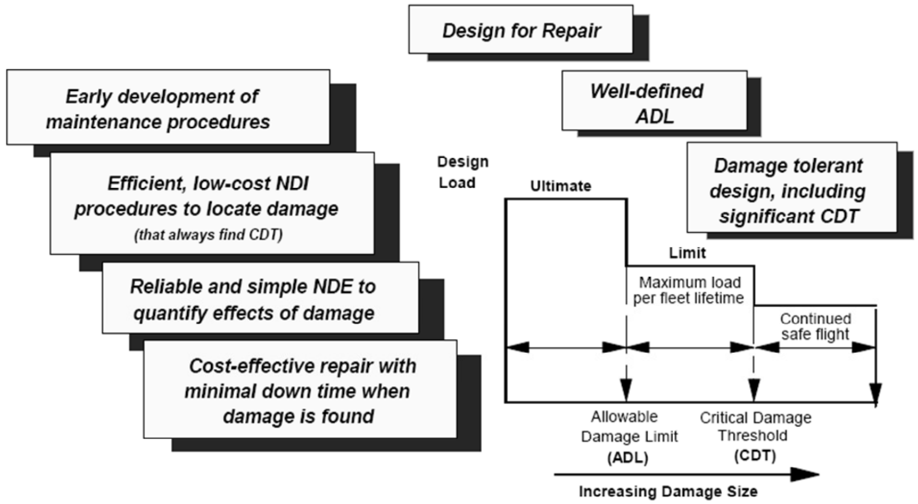
The component needs to maintain its structural integrity (strength, stiffness, environmental resistance) throughout its lifetime

Repairable

Repair philosophies have to be developed during the design phase (restore strength and design functionality)

Maintainable

Simple assemblies, easy access for internal inspection to minimize damage during maintenance (ADL, CDT, qualified repair materials, specifications, tooling, NDI)

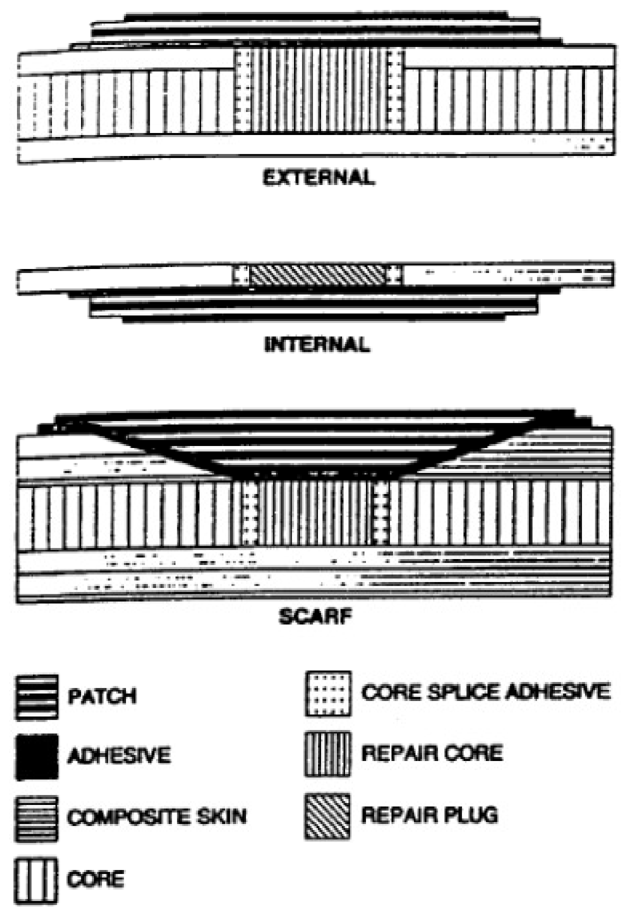


DESIGN LOAD AND DAMAGE CONSIDERATIONS FOR DURABILITY AND DESIGN [2]

REFERENCES:
1- DESIGN OF DURABLE, REPAIRABLE AND MAINTAINABLE AIRCRAFT COMPONENTS – SAE AE 27
2-COMPOSITE MATERIALS HANDBOOK, VOLUME 3-G, "POLYMER MATRIX COMPOSITES MATERIAL USAGE, DESIGN AND ANALYSIS"

Bonded Repairs to Composite Structures

- A repair has the objective of restoring a damaged structure to an acceptable capability in terms of strength, durability, stiffness, functional performance, safety, cosmetic appearance or service life [1]
- A repaired structure must restore the certification basis of the original construction, i.e. must be as airworthy as the original unrepaired structure: the repaired part must be capable of sustaining limit load without permanent deformation, and ultimate load without catastrophic failure
- The repaired part must also be durable, i.e., must sustain its service loads for periods exceeding the expected life of the aircraft and damage tolerant, i.e., with a given damage, the structure must sustain its design loads for a reasonable period without the Damage reaching a critical size that could result in the loss of the part [2]
- Designing for repairability is an essential element in the effective use of composite materials in aircraft structures. It is important that the repair philosophy be set during the conceptual design stage and that the repair designs be developed along with the component design [3].



References:

1-Composite Materials Handbook, volume 3-G, "Polymer Matrix Composites material usage, design and analysis"

2-Davis, M.J., et al."A rigorous approach to certification of adhesive bonded repairs," FAA workshop on Certification of Adhesive Bonded Structures and Repairs, Seattle, WA, 16-18 June 2004.

3-Composite Materials Handbook, volume 3-G, "Polymer Matrix Composites material usage, design and analysis"

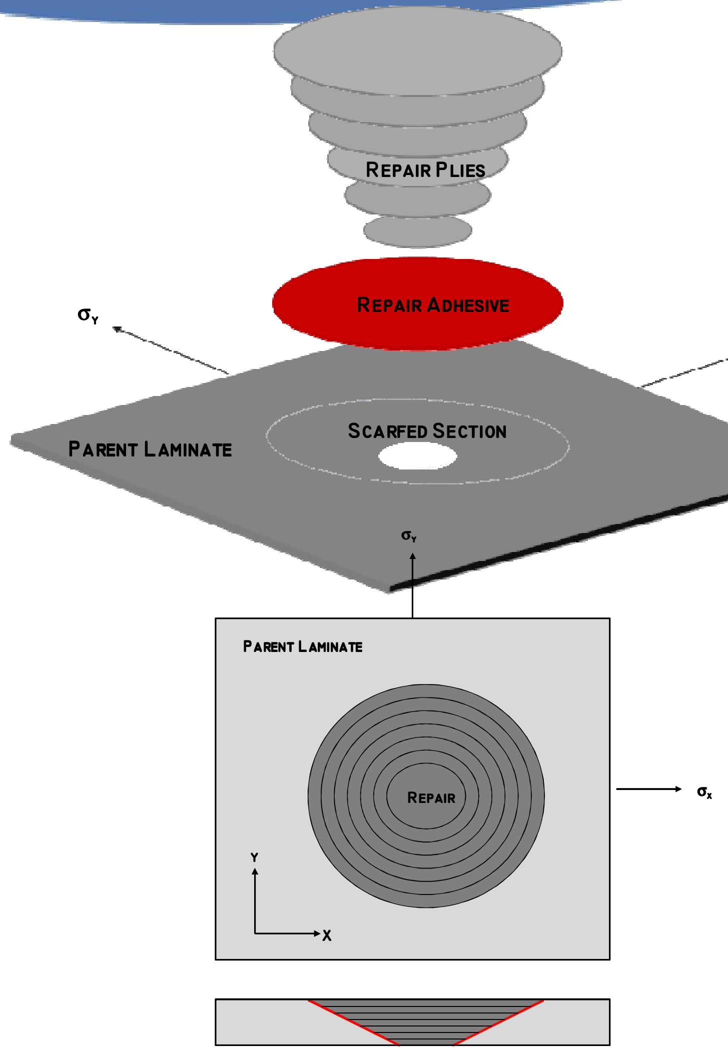
Bonded Repairs- Advantages/ Limitations

Bonded Repairs, advantages

- can restore a composite structure's original strength
- More fatigue resistant due to the absence of stress concentrations that occur at fasteners
- corrosion resistant
- lighter than bolted repairs due to the absence of fastener hardware
- Cost Effective
- Smooth aerodynamic contours

Bonded Repairs, Limitations

- No Redundancy in the Load Path
- Load Capability Dependent on Adhesive Properties
- Lack of NDI Methods that can provide absolute bond assurance
- Process Dependent



CECAM JAMS JOINT ADVANCED MATERIALS & STRUCTURES CENTER OF EXCELLENCE AMTAS Advanced Materials in Transport Aircraft Structures

Introduction – Current FARs

- For any bonded joint, 14 CFR 23.573 states in part "the failure of which would result in catastrophic loss of the airplane, **the limit load capacity must be substantiated** by one of the following methods [1]"

- AC 20-107B- Proof of structure – Static : "**the effects of repeated loading and environmental exposure** which may result in material property degradation should be addressed in the static strength evaluation."

- AC 20-107B- Proof of structure – Fatigue and Damage Tolerance : "Such evaluation must show that **catastrophic failure due to fatigue, environmental effects, manufacturing defects or accidental damage will be avoided** throughout the operational life of the aircraft"

- AC 20-107B- Proof of structure – Continued Airworthiness "Of particular safety concerns are **the issues associated with bond material capabilities, bond surface preparation, cure thermal management**."

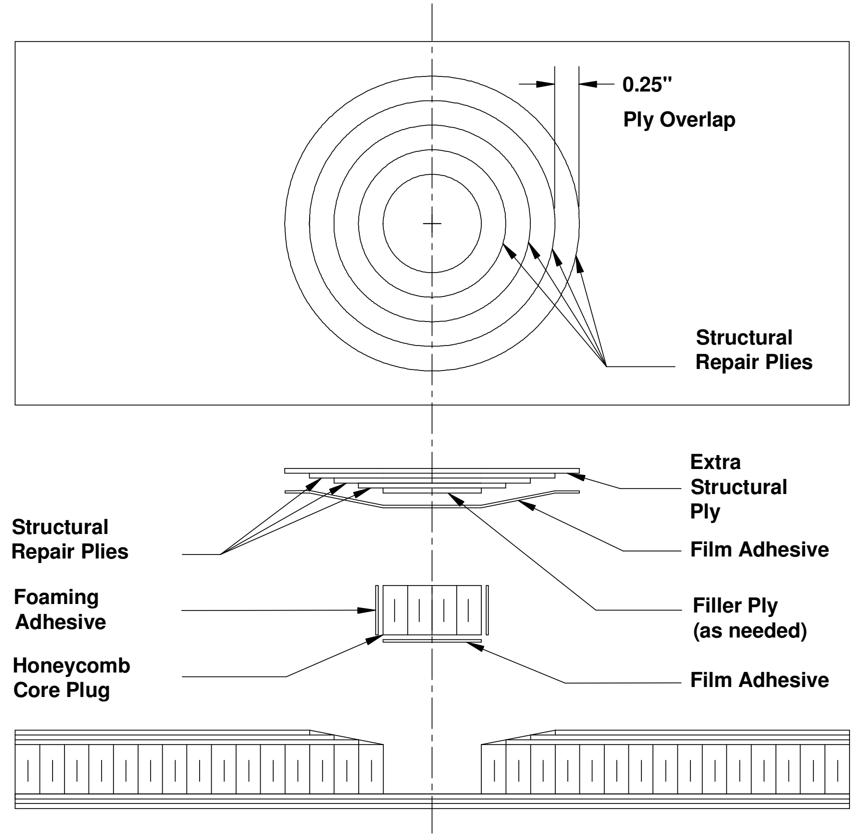
References

1- AC 20-107B 9/8/2009, 14 CFR parts 23, 25, 27, 29

2- Davis, M.J., et al."A rigorous approach to certification of adhesive bonded repairs," FAA workshop on Certification of Adhesive Bonded Structures and Repairs, Seattle, WA, 16-18 June 2004.

Research Program Objectives

- To evaluate the static strength and residual strength after fatigue of OEM vs field bonded repairs applied to composite sandwich structures, performed at different operator depots.
  - Repair method evaluation (OEM/CACRC)
  - Variability/ repeatability of repairs performed at different depots
  - Evaluation of existing CACRC standards for repair implementation/ technician training
  - Residual strength/ environmental durability
- To evaluate the static strength and residual strength after fatigue of OEM vs field bonded repairs subjected to impact damage and defective process parameters



Scarf Repair Applied to a sandwich structure

Some Lessons Learned – Bonded Repair Research

- The integrity of the bonded repair depends on the integrity of the bonded interface which is directly dependent on the process; a clean chemically active surface prior to bonding is key to the integrity of a bonded repair (bonded repairs are process dependent)

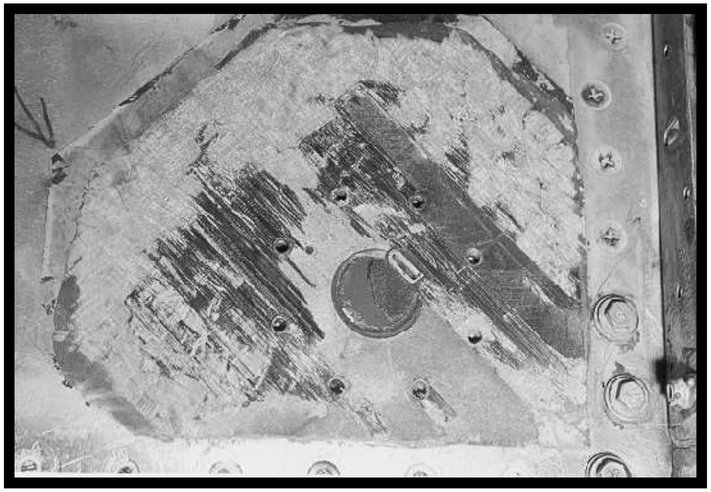
- Deficient processes will yield a defective repair: Inadequate process may yield ***porous*** repairs, weak bonds due to improper surface preparation, pre-bond contamination, ineffective/ inadequate cure cycle, improper choice of materials (adhesive systems for example) which may have disastrous implications of the residual strength of the bonded structure

- Training and Certification of repair personnel: Repair technician training directly affects the structural integrity of a bonded repair. Only certified technicians should perform bonded repairs on composite structures

- A robust process substantiation for the systems used in a given repair application is necessary as different systems may have different performance and chemical characteristics

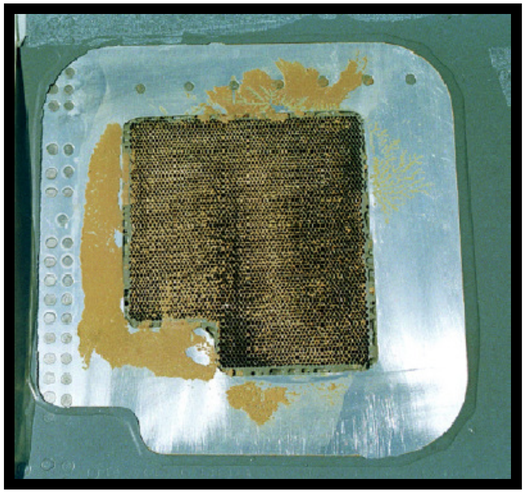
- OEM/ field repair system substantiation: while OEM systems may be used in the factory environment, with the possibility of processing parts in the autoclave using the parent systems, these systems (requiring autoclave pressure for optimum performance) ***cannot*** be used in maintenance depots.

In-Service Experience With Bonded Structures and Repairs



Boron composite Patch Failure [1]

Cause: pre-bond moisture (microvoids in adhesive), all patches that failed were applied in Malaysia



Patch Failure In Flight [1]

Cause: ineffective surface preparation, adhesive undercure

Adhesion Failure of a composite Patch [1]

Cause: Silicone treated peel ply

References:

1-Davis, M.J."FAA Workshop on Best Practise In Adhesive Bonding," 2004. 2-FAA AD2010-26-54

In-Service Experience With Bonded Structures and Repairs

Lessons Learned:

Outstanding performance where reliable processes were used

Rigorous surface preparation yielding a **clean chemically active** interface is necessary for a durable bond

Surface preparation must yield an **interface resistant** to degradation

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)

Research Methodology

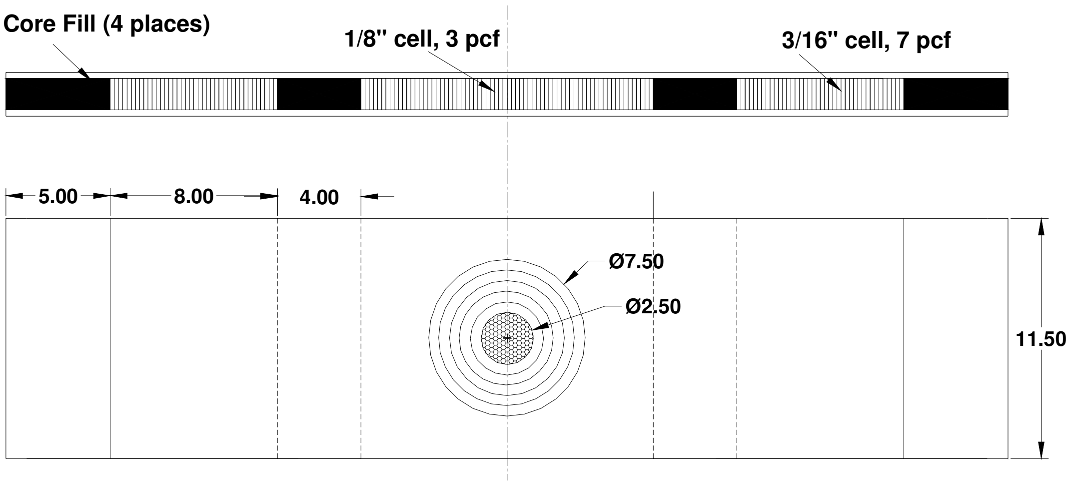
Sandwich Specimen Configuration

- 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

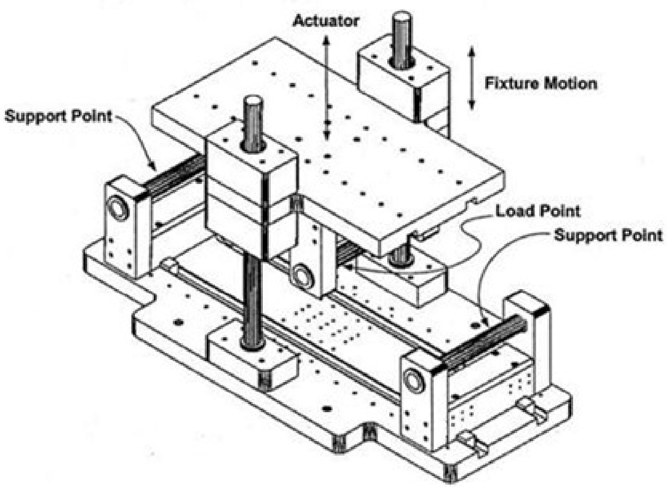
- Parent Material:
  T300/ 934 3KPW with FM 377S adhesive (OEM)

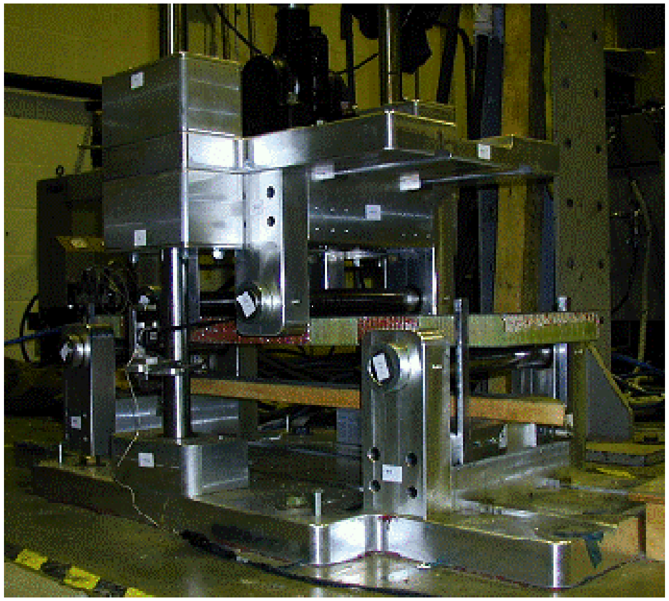
- Repair Materials:
  CACRC repair 1: Hexcel M20 PW (250°F cure) with EA9695/ FM300-2 adhesive (AMS 3970)
  CACRC repair 2 (wet lay-up): Tenax HTA 5131 200tex f3000t0 fabric with Epocast 52A/B laminating resin (AMS 2980)
  OEM repair 1: using parent system (350°F cure)
  OEM repair 2 (wet lay-up): Tenax HTA 5131 200tex f3000t0 fabric with EA9396 C2 laminating resin and EA9696 adhesive

Research Methodology



Large Beam Configuration





Large Beam Test Set-Up

Loading span 18", support span 42"

Research Methodology - Test Matrix

Repair Station	Coupon Configuration	Repair Material	Loading Mode	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		3	3
Field Station 1	Repair/ 2.5" hole	CACRC-R2	Compression		3	3
Field Station 2	Repair/ 2.5" hole	CACRC-R1	Compression		3	3
Field Station 2	Repair/ 2.5" hole	CACRC-R2	Compression		3	3
Field Station 3	Repair/ 2.5" hole	CACRC-R1	Compression		3	3
Field Station 3	Repair/ 2.5" hole	CACRC-R2	Compression		3	3
Field Station 4	Repair/ 2.5" hole	CACRC-R1	Compression		3	3
Field Station 4	Repair/ 2.5" hole	CACRC-R2	Compression		3	3
						105

OEM-R1 T300/934 w FM377 adhesive

OEM-R2 EA 9396 C2 wet lay-up w EA9696 adhesive

CACRC- R1 M20PW with EA9695 adhesive

CACRC- R2 Epocast 52A/B wet lay-up

Research Methodology – Panel Manufacture

OEM process approval (OEM specs) obtained before manufacturing the panels

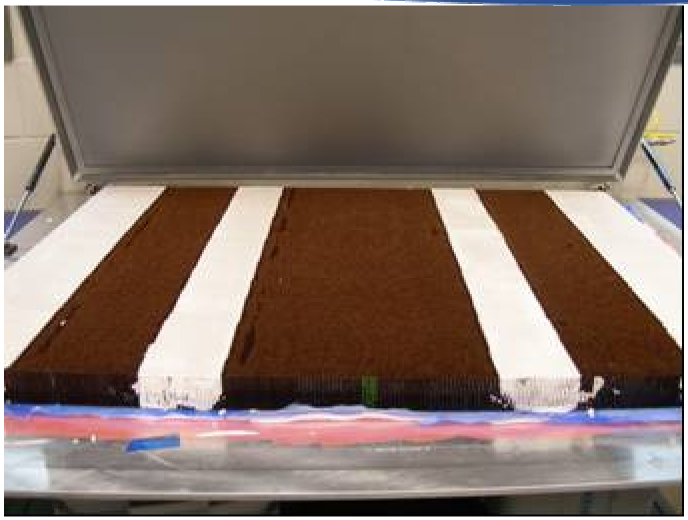
Facesheet 1 Lay-Up

Facesheet 1 Adhesive Application

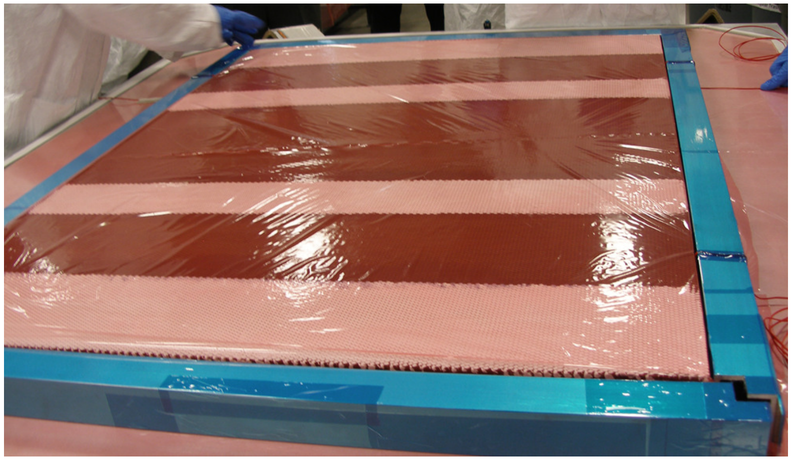
Core Potting using Corfill 658

Core Potting, vacuum application

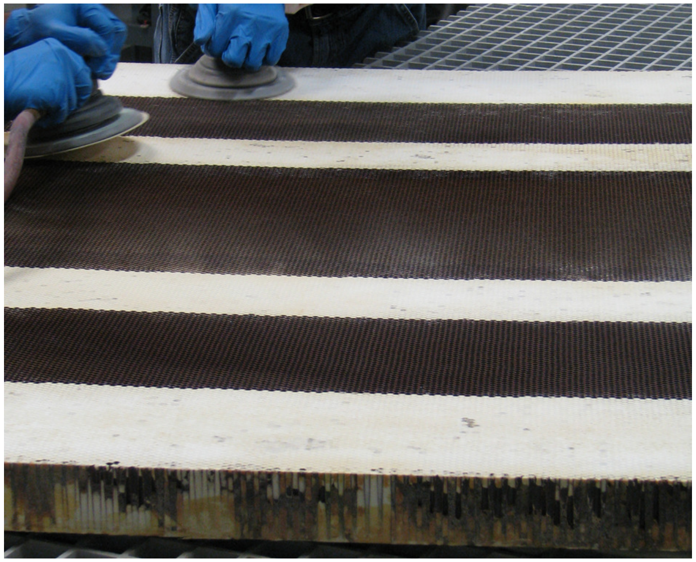
Research Methodology – Panel Manufacture

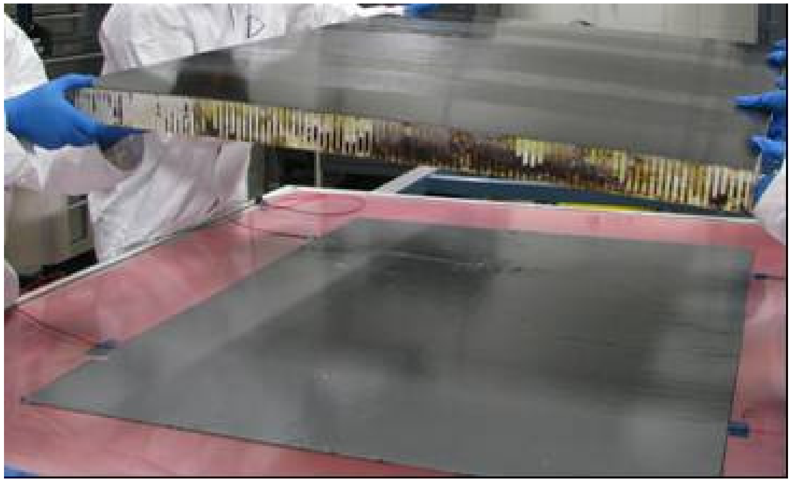


Potted Panel



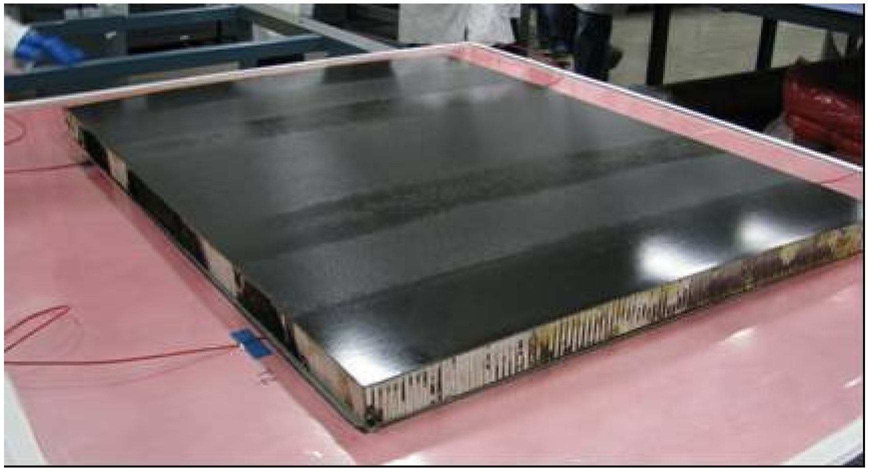
Release Film and Fairing Bar Application

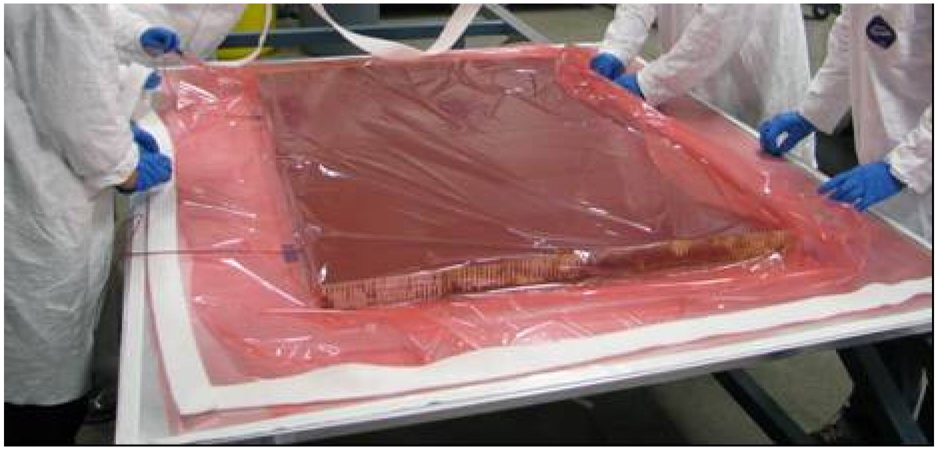


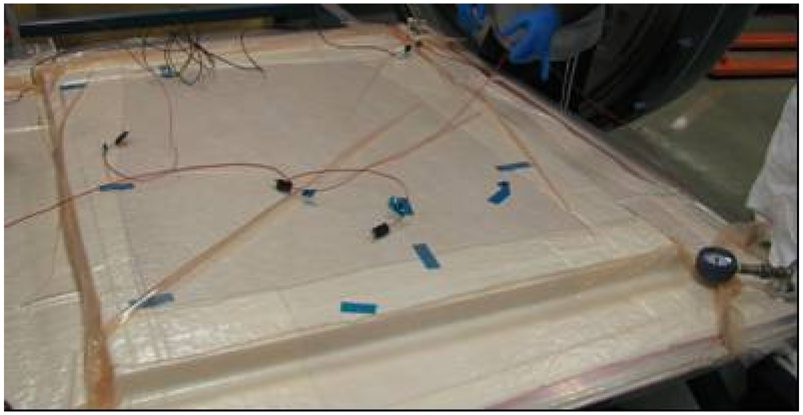


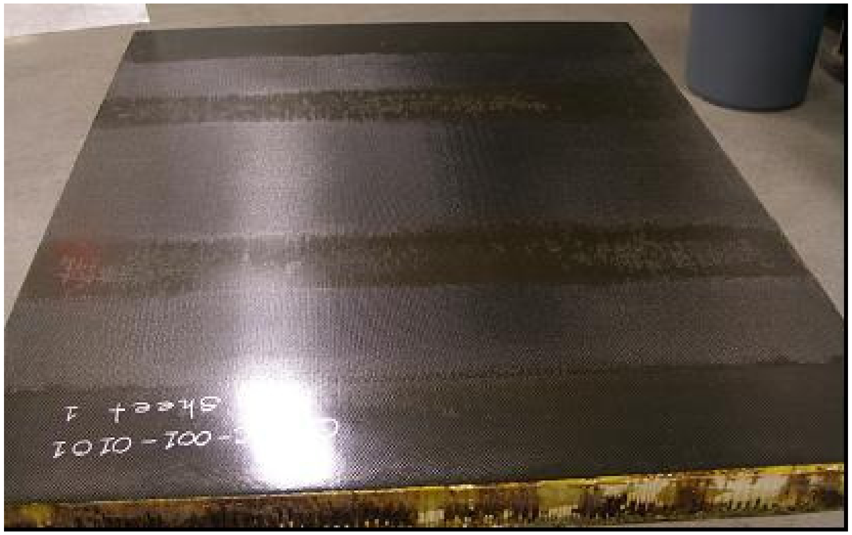
Final Assembly

Research Methodology – Panel Manufacture

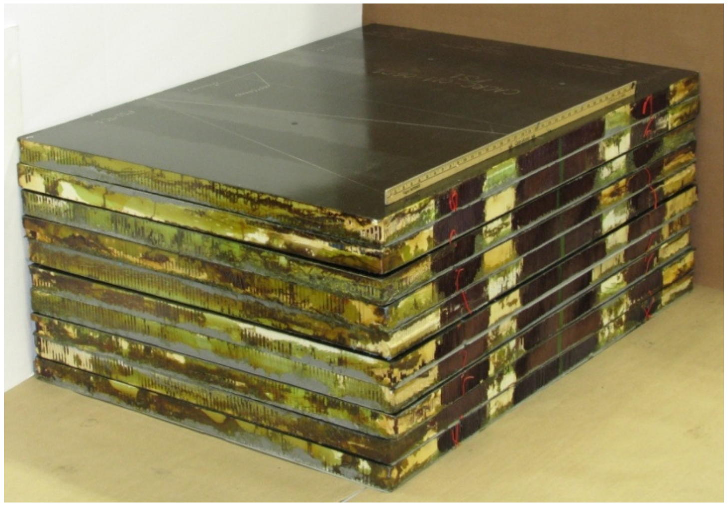


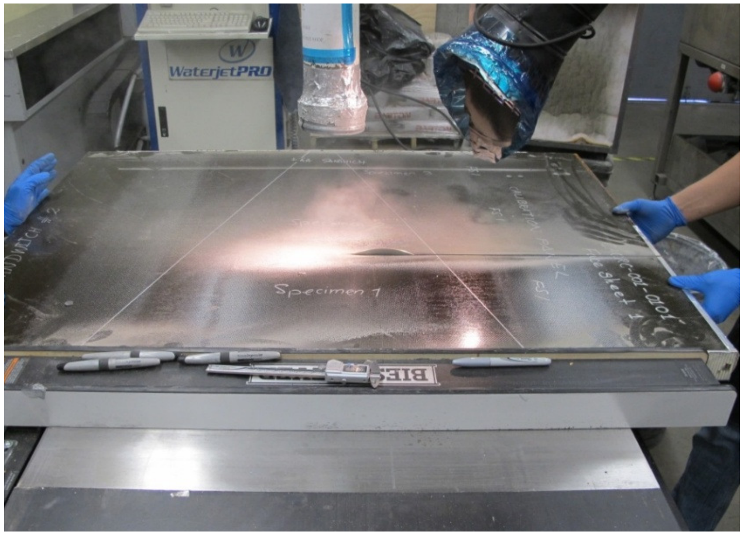


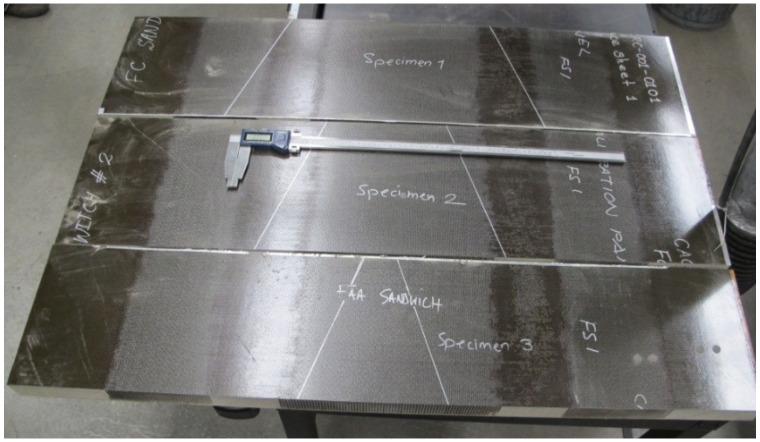




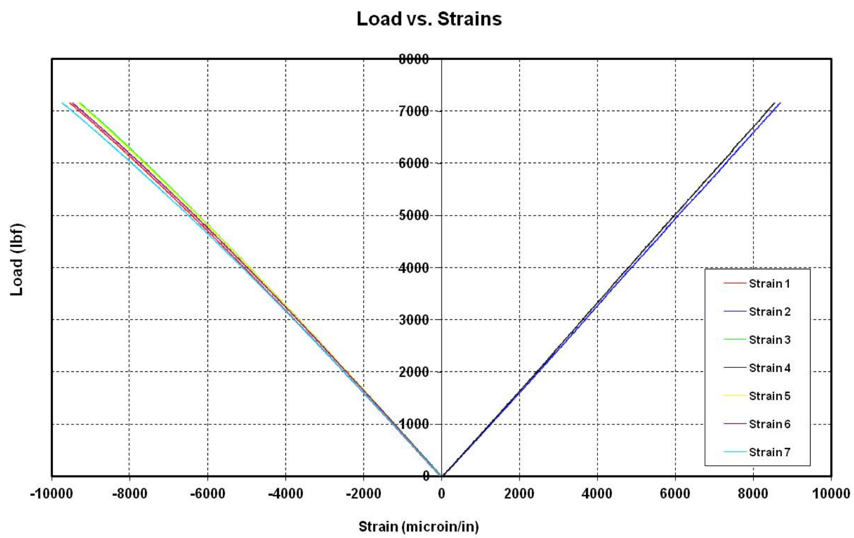
Specimen Machining







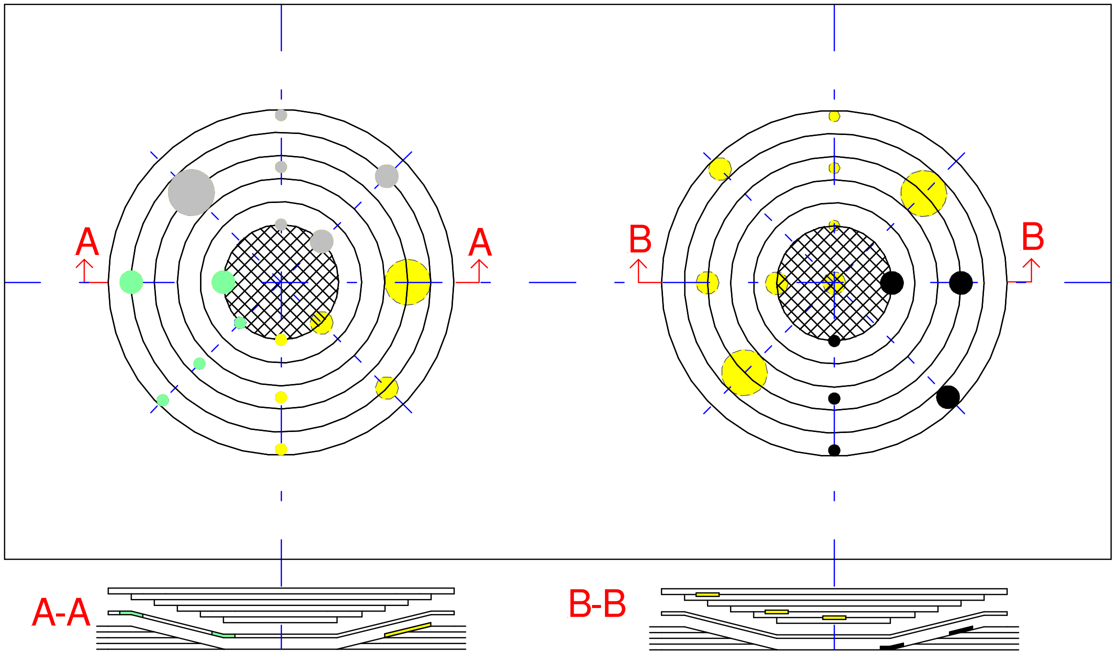
Specimen Design Validation



- Good correlation between experimental results and predictions
- Average failure strains (-9335με and 8492με)

Research Methodology – NDI (SNL)

- MAUS V pulse echo
- MAUS V resonance
- OmniScan Phased Array
- TTU
- IR Thermography
- Mechanical impedance analysis
- Automated tap test devices: Woodpecker, Digital Tap Tester and the CATT
- Shearography



Reference Standards

Status – Planned Activities

- Large Beam Machining Complete
- Repair Material procurement in progress
  (CACRC materials have shipped from Europe and have been delivered)
- Repair procedure preparation in progress
- OEM repairs (NIAR/ NCAT)
- CACRC repairs (May 2012, 4 airline depots)
- NDI reference standard manufacture
- Inspection of Repaired panels
- Specimen Instrumentation
- Environmental Conditioning
- Chamber design and manufacture
- Mechanical Testing (static and cyclic)

Process Parameter and Contamination Evaluation

- Small beams, 4" x 24" with the repair tested in compression and Tension 1" thick core, 4-ply facesheets, 3/16" core cell size (8 pcf)
- Parent Material:

  T300/ 934 3KPW with FM 377S adhesive (OEM)
- Repair Materials:

  CACRC repair 1: Hexcel M20 PW (250°F cure) with EA9695/ FM300-2 adhesive (AMS 3970)

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

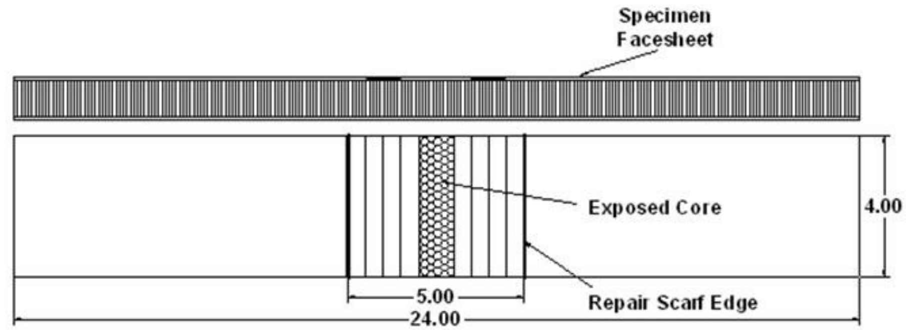
  OEM repair 1: using parent system (350°F cure)

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

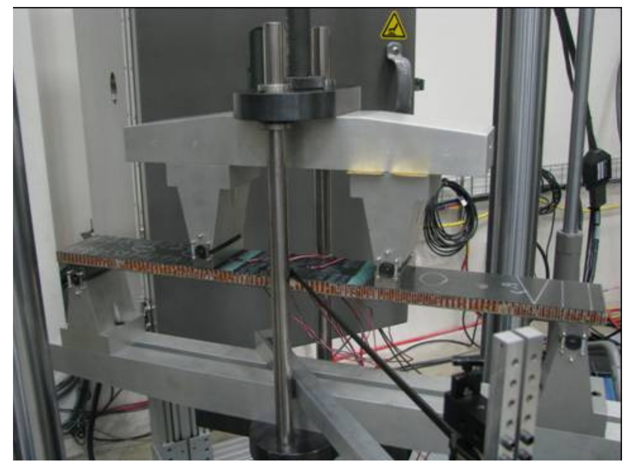
Process Parameter and Contamination Evaluation

Variables Investigated:

- Different Repair Systems
- CACRC vs OEM Repairs
- Soft vs Stiff Repairs
- Impact (BVID)/Inclusions
- Contaminant 1: pre-bond moisture
- Contaminant 2: pre-bond moisture w several drying cycles
- Contaminant 3: Skydrol + water
- Cure Cycle Deviation 1: lower temperature cure, longer dwell
- Cure Cycle Deviation 2: fast ramp up rate
- Loading Modes: Tension vs Compression
- Different Environments



Small Beam Configuration



Small Beam Test Set-Up

Process Parameter and Contamination Evaluation

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

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Looking Forward

<u>Benefits to Aviation</u>

- To investigate the effectiveness of "OEM environment" vs field repairs and the variability due to repair implementation at various operator depots
- To understand the environmental durability and the residual strength after fatigue of bonded repairs subjected to various processes and environments
- To identify key elements in the implementation of bonded repairs that ensure repeatability and structural integrity of these repairs
- To provide recommendations pertaining to repair technician training and repair process control

Acknowledgments

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- Chathuranga Kuruppuarachchige
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- Indika Thevarapperuma

End of Presentation.

Thank you.

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