SPIRIT AEROSYSTEMS ™

"Examples of Substantiation Testing and Documents to Support Large Areas of Composite Repair"

2015 FAA/Bombardier/TCCA/EASA/Industry Composite Transport Damage Toleranc and Maintenance Workshop

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The Importance of Substantiation to DER Composite Repair Approval

Large area repairs are becoming more common

Damage is not always a result of an impact often times making the repair approach more intricate:

Jim Epperson

The Importance of Substantiation to DER Composite Repair Approval

- Repair techniques have not changed/varied much over the years, our equipment has improved but for the most part we are still performing same step back repair methodologies.
- What has changed is the increased use of composites in primary structure creating within the industry the need for detailed substantiation analysis in support of the repair. Still using the standard material removal and replacement approach, but highly dependent on the properties of a material undergoing one of a select number of processing parameters.
- The major challenge in the absences of having a MMPDS composites equivalent (i.e...count the rivets in an alloy with known properties), is how does one justify the use of an alternate curing process (time, pressure, dwell) or the use of a substitute material system, or even expanded repair size limits? No matter how elemental the deviation is, when applied to primary structure surety of the substantiation report integrity is paramount to the issuance of a FAA DER approval.

Jim Epperson

The Importance of Substantiation to DER Composite Repair Approval

- What are the options short of going back to the OEM for providing a substantiation analysis that would allow a DER to be able to approve a complex composite repair?
  - The simplest solution would be to share material allowables. Not very likely scenario
- Substantiation complexity is driving the industry into specialty cells of engineering resources:
  - Willing to take on building allowances data bases for customer specific aircraft.
  - Willing to invest/coop in test lab equipment & personnel.
  - Willing to trek the desert in search of scrapped components that can be used for data mining.
  - Have a customer base that after years of being pillaged by the only OEM option of buying a new part that is willing to invest in the creation of the needed IP in order to support their fleets more economical by utilizing DER repair opportunity.
- When an organization has the aforementioned resource data, then there are multiple avenues of substantial repair opportunities. All of which can be easily FAA DER approved.
  - Futuristically, this could lead to data sharing coops and MRO's with appended engineering expertise in composite repair analysis.

Jim Epperson

Examples of Practiced Repair – Past Experience, SB0078

In 2005/2006 time frame, Spirit assisted Boeing by designing a repair kit to comply a condition that existed on 18 aircraft, 72 thrust reverser inner walls.

Service Bulletin 777-SB0078 was released, and 18 aircraft at 5 foreign carriers were identified to have an area between 35-36 square feet removed and replaced with structural materials of the same genre, for increased performance.

Raw materials were controlled by existing Material Specifications

The repair plies were kitted and prepared to a released Engineering Dataset

The repair plies were cut and assembled using Production Processes to a known Production Process Specification using Production Tools, Tapes, and Templates

Seed Units were built so that units in need of compliance could be removed from the wing and the airplane could return to service – coordinated logistics of the event were arranged at each individual airline, holding tools and transport tools were included

Spirit traveled a practiced and proficient repair technician crew to each site to perform removals, repair, and replacement of the thrust reverser elements

Spirit arrived with a known NDI plan, and a NDI standard on site, to perform capable NDI after the repair was completed – every unit

Substantiation testing included coupon and element level testing

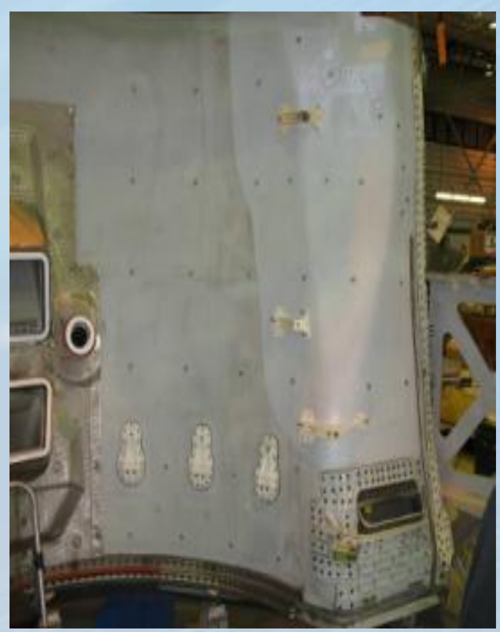
Test Results, Structural Analysis, and Repair Methodology were all recorded in a completed Document, MAA7-70023-1 which was later used for Approval

Examples of Practiced Repair Kits – Past Experience, SB0078

Large Area Repair for Inner Wall Compliance (72)

Necessary Tooling to get T/R into Repair Position

Repair Area = 33 and 35 sq ft (LH & RH)
28,000 cycles, 80,000 hrs, on the oldest repair
Performed 6/9/2006 thru 4/2008



Note – Repair in "Sections" vs One Large Area

2005 thru 2009

Examples of Practiced Repair Kits

Large Area Repair for Inner Wall Compliance (72)

Smoothing kit into sanded recess, tool located and template aligned

Example of consolidated repair kit, this one was done out of autoclave

Placement of consolidated repair kit, onto structure

Result – Kit is ready to bag and cure – total time involved in place-ment --7 mins

Lesson Learned: A well prepared kit drastically reduces repair time

Note – Repair in "Sections" vs One Large Area

2005 thru 2009

Substantiation – Structural Test Coupons

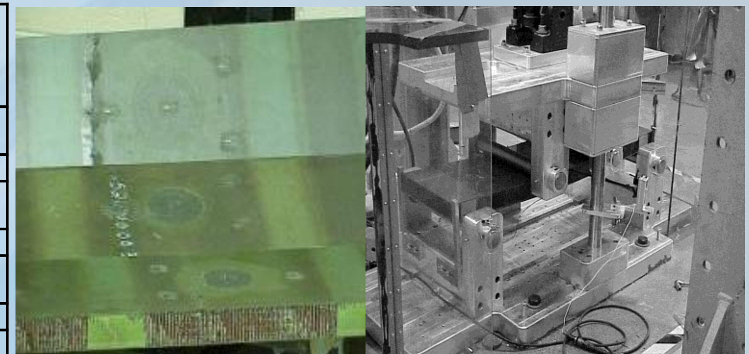
Example Test Matrix: Tension, Static, RT

Tension

Compression

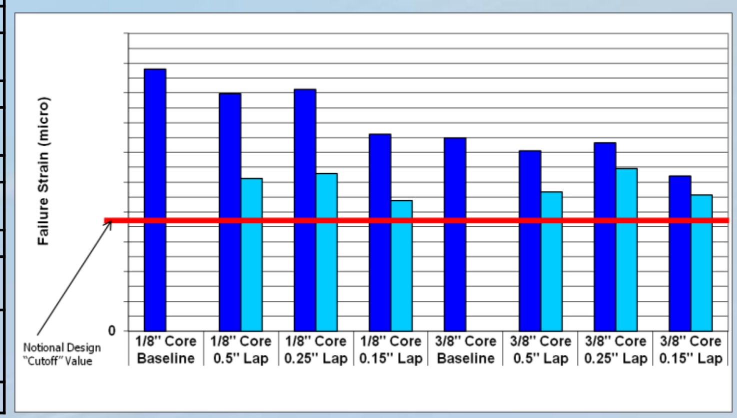
Loading Modes	Specimen Configuration	Repair Type	Repair Material	BVID	Total Quantity
Tension (5.5 x 11.5)	Repair Baseline 0.50 inch/ply overlap using 3/8 inch cell core	1 D W/D = 1	Gr/Ep 3K-70-PW, with Adhesive Gr 5, over Core C1, TIII, Gr 4.5 core	No Impact	5
				Impact	5
		2 D W/D = 3.7		No Impact	5
				Impact	5
	Repair Baseline 0.50 inch/ply overlap using 1/8 inch cell core	1 D W/D = 1	Gr/Ep 3K-70-PW, with Adhesive Gr 5, over Core C6, TV, Gr 3 core	No Impact	5
				Impact	5
		2 D W/D = 3.7		No Impact	5
				Impact	5
	0.25inch/ply overlap using 3/8 inch cell core	1 D W/D = 1	Gr/Ep, 3K-70-PW, with Adhesive Gr 5, over Core C1, TIII, Gr 4.5 core	No Impact	5
				Impact	5
		2 D W/D = 3.7		No Impact	5
				Impact	5
	0.25 inch /ply overlap using 1/8 inch cell core	1 D W/D = 1	Gr/Ep, 3K-70-PW, with Adhesive Gr 5, over Core C6, TV, Gr 3 core	No Impact	5
				Impact	5
		2 D W/D = 3.7		No Impact	5
				Impact	5
	0.15 inch/ply overlap using 3/8 inch cell core	1 D W/D = 1	Gr/Ep, 3K-70-PW, with Adhesive Gr 5, over Core C1, TIII, Gr 4.5 core	No Impact	5
				Impact	5
		2 D W/D = 3.7		No Impact	5
				Impact	5
	0.15 inch /ply overlap using 1/8 inch cell core	1 D W/D = 1	Gr/Ep, 3K-70-PW, with AdhesiveGr 5, over Core C6, TV, Gr 3 core	No Impact	5
				Impact	5
		2 D W/D = 3.7		No Impact	5
				Impact	5
	Impact Calibration Specimens	2D .25"/ply 3/8" cell core	Gr/Ep, 3K-70-PW, with Adhesive Gr 5, core as noted above	Impact	4
		2D .25"/ply 1/8"cell core		Impact	4
	TOTAL TENSION SPECIMENS				128

Note: Current Validation Matrix coupon count is 278 coupons



Large Beam Bending

Test Results



In 2014 time frame, Spirit designed, tested, and proved repair methods for a repair kit to repair heat damage on existing and future 737NG thrust reverser inner walls, detailed in 737NG SB-1079

Service Bulletins 1079, 1080, 1083, 1085, 1089, and eventually AD2012-05-02 were released to correct the heat damage condition for every thrust reverser inner wall manufactured from 1993-2011 (circa)

The size of the repair area is 20-22 square feet depending on whether it is a left or right hand panel

Raw materials were controlled by existing Material Specifications

The repair plies were kitted and prepared to a released Engineering Dataset

The repair plies were cut and assembled using Production Processes to a known Production Process Specification using Designed Tools, Tapes, and Templates

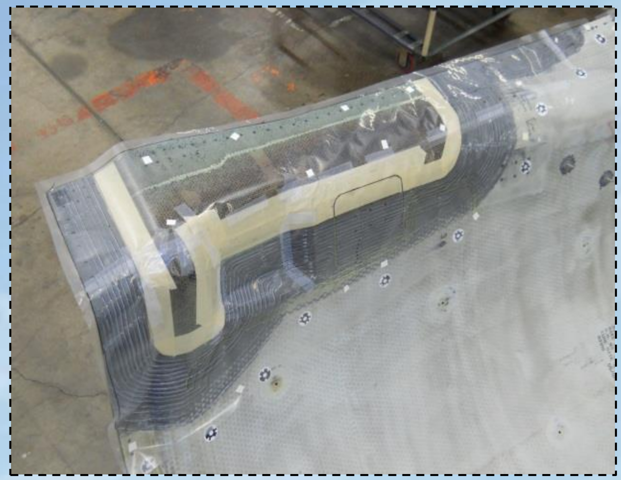
Spirit offers to travel a practiced and proficient repair technician crew to each site to perform removals, repair, and replacement of the thrust reverser elements, however in this instance, many of the MROs have done enough of these that they are already very practiced and proficient

Spirit provides a known NDI plan, and a NDI standard on site, to perform capable NDI after the repair was completed – every unit

Substantiation testing included coupon and element level testing

Test Results, Structural Analysis, and Repair Methodology were all recorded in a group of completed Documents, MAA7-71277-1, MAA7-71277-2, and MAA7-71277-3, submitted for global AMOC approval.

Currently working to Make a SB/AD Repair Kit


Compared Large Number
of Damaged Inner walls:
-Damage location was consistent
-Damage area (size) was consistent
-Found correlation between damage size and time on wing
-From data, could categorize two basic geometry needs for a repair kit
(Reviewed **more than 600 panels**)

Within a reasonable tolerance, learned we could categorize damage size
- Repeatable Geometry has the opportunity for a designed repair kit

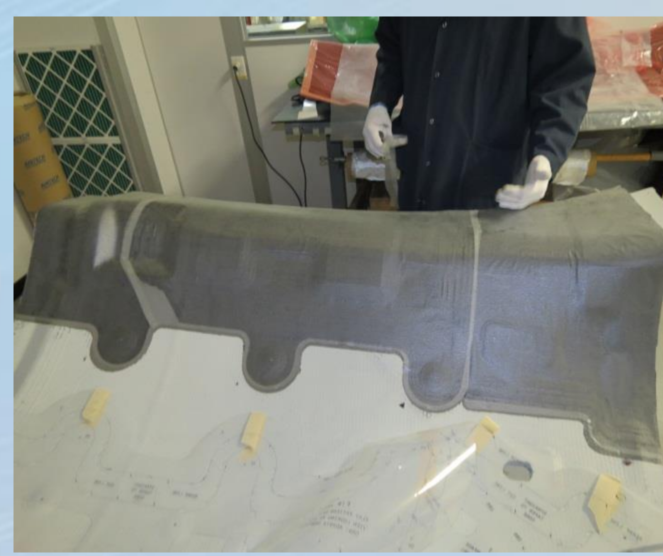
The “Practice” of Making a SB/AD Repair Kit

Repair Kit arrives on contoured Shipping fixture

Forward Ply Kit

Aft Ply Kit

Middle Ply Kit



Kit Located – Ready for Cure

The “Practice” of Making a SB/AD Repair Kit

Finished Panel, after heat blanket cure

Clean NDI

Substantiation Coupons for a SB/AD Repair Kit

This is what Structural Substantiation Looks Like

Substantial Investment

Took about 1 year to fabricate, and test to failure, all coupons

Variables included in the test plan:

Spliced Heat Blankets
One Side Heat Source
Heat on both Sides
Autoclave sub-strate
Heat blanket cured sub-strate
Baseline – Autoclave Cured
Repaired – OoA Cured

Example of Different Test Types for a SB/AD Repair Kit


Tension - Laminate


Tension – Sandwich, Rpr

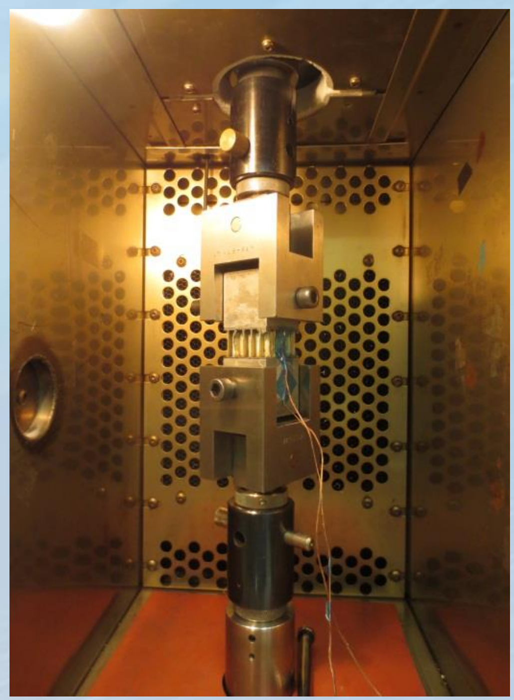

Tension – Sandwich, LD

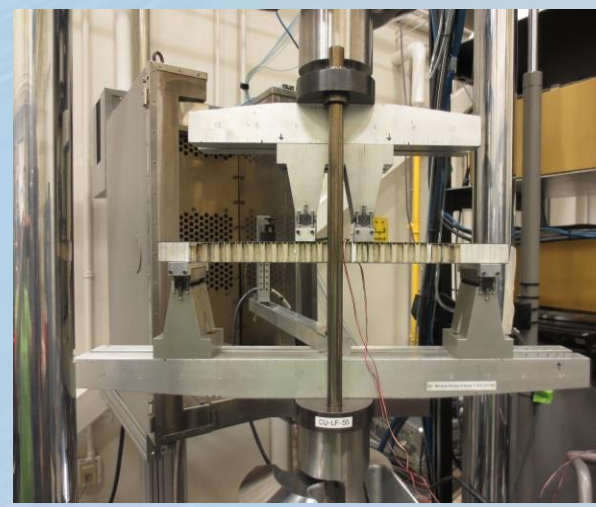

Tension – Sandwich, HD


Flex – Sandwich,


Tension - Sandwich


Pin Bearing


Flat-Wise Tension


Flex – Sandwich, LD

Common Threads through both Large Area Repair Examples are:

Controlling the Raw Material as if it was being used in Production

Controlling the creation of the repair kit as if it was being used in Production

Performed Engineering Dataset definition as if it was any other FAR24/25 flight worthy component

Made the repair technicians practice the repair method

Created Tools, Templates, and Processes identical to Production methods

Provides a known NDI plan, and a NDI standard just like Production

Substantiation testing included coupon and element level testing

Test Results, Structural Analysis, and Repair Methodology were all recorded in a group of completed Documents - Referenced

Basically, adopting all the things we know how to do to achieve certification, and applying that knowledge to a repair event

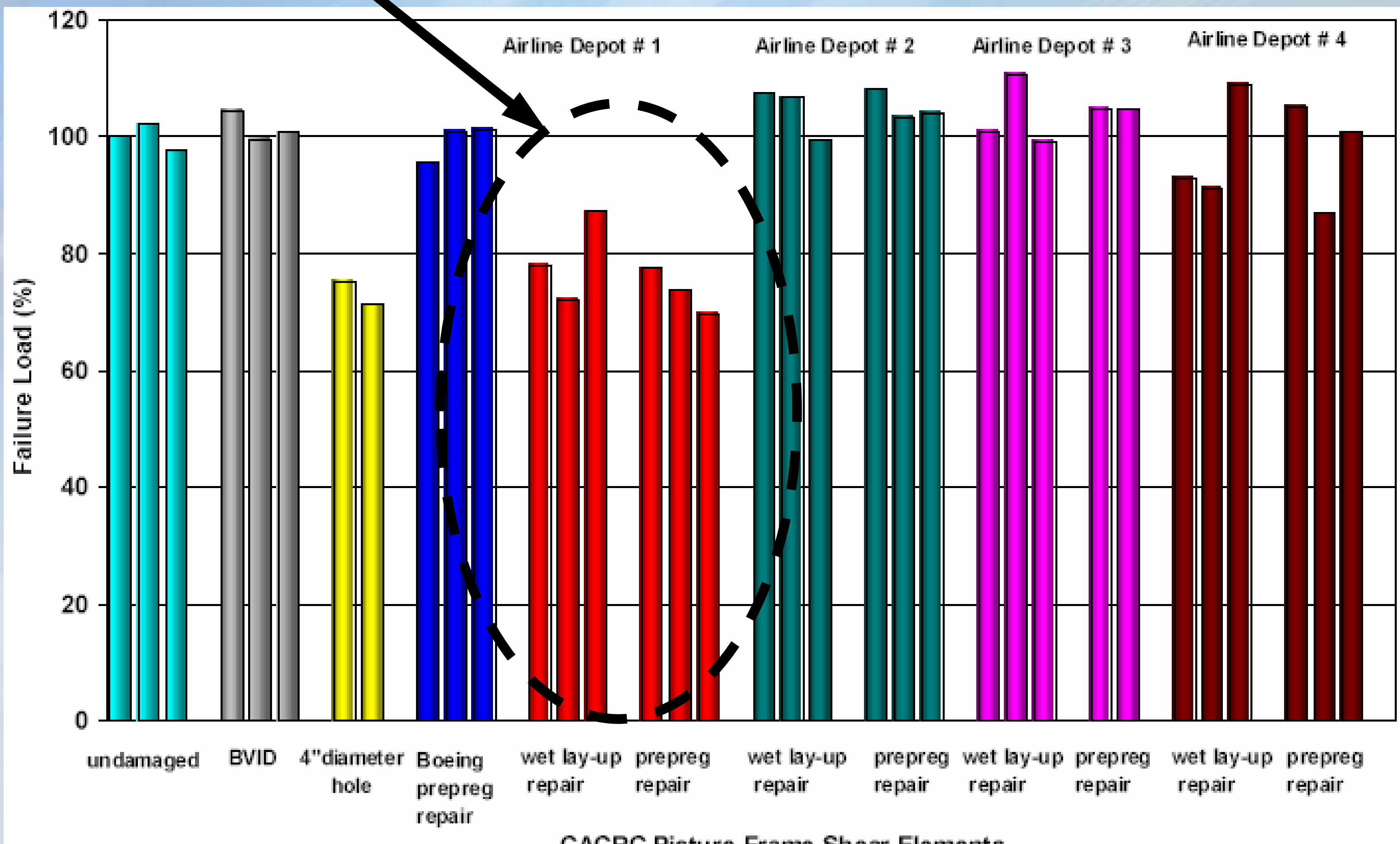
What lessons can be taken forward to begin to address Primary Structure, and its eventual Repair??

Adhesive Bond Strength Dependence On Process Evidenced By CACRC Round Robin

- DOT/FAA/AR-03/74, February 2004

Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

Cure error reported after test results reported



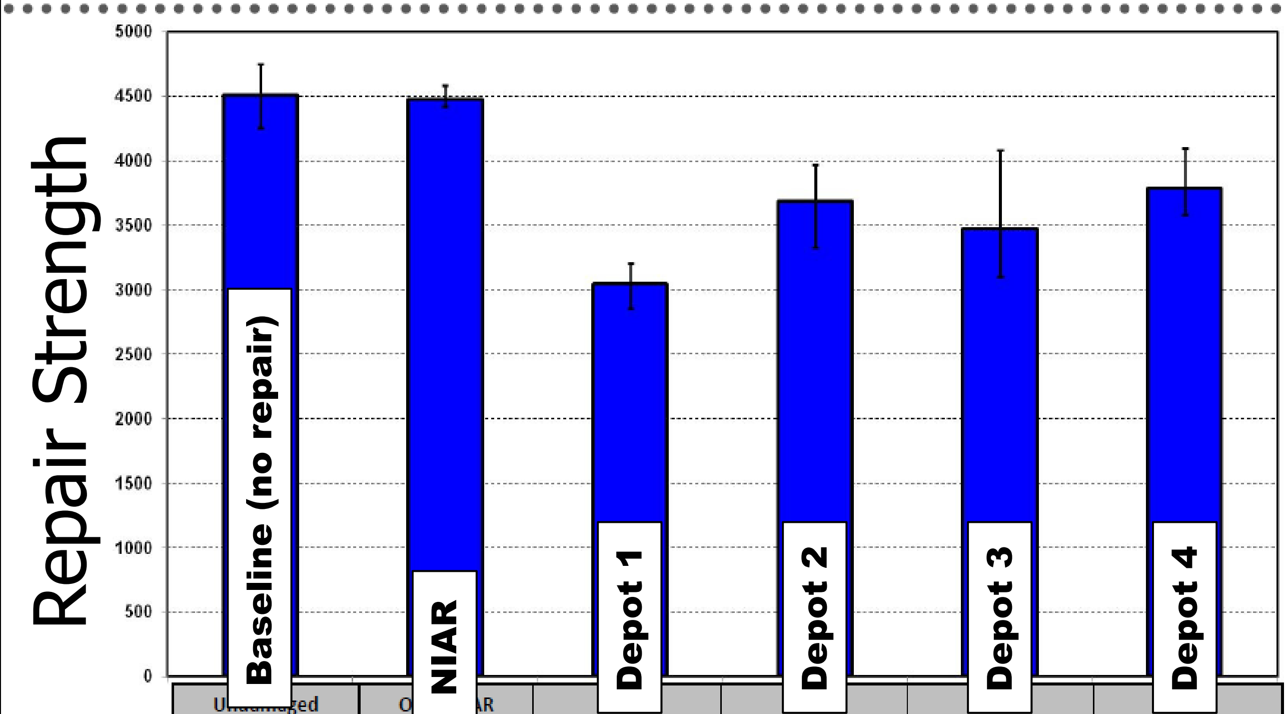
2014 FAA/CACRC Round Robin Study

CACRC = *Commercial Aircraft Composites Repair Committee*, SAE/International

Courtesy Michael Borgman
Nov 2014 FAA workshop
Bonded Repair Initiative

C:\Ilcewicz\Research\WSU\Repair-CACRC_2011+\Supportability_80714.pdf

Preliminary Results – CACRC Prepreg Repairs using M20 PW/ EA9695



Baseline (no repair)	NIAR	Depot 1	Depot 2	Depot 3	Depot 4
100%	99%	68%	82%	77%	84%
-5872με	-6349με	-4254με	-5076με	-4570με	-5240με

- Preliminary ETW data, repair elements tested at 180°F (data available to date)
- Failure loads normalized with respect to ETW undamaged element strength capability

2014 evidence of inconsistent repair structural performance across repair depots (lowest results show only 68% strength restoration)

AMC 25.571(a), (b) and (e)
Damage Tolerance and Fatigue Evaluation of Structure

- Principal Structural Elements

Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

2.2 *Identification of Principal Structural Elements*. Principal structural elements are those which contribute significantly to carrying flight, ground, and pressurisation loads, and whose failure could result in catastrophic failure of the aeroplane. Typical examples of such elements are as follows:

2.2.1 *Wing and empennage*

a. Control surfaces, slats, flaps and their attachment hinges and fittings;

b. Integrally stiffened plates;

c. Primary fittings;

d. Principal splices;

e. Skin or reinforcement around cutouts or discontinuities;

f. Skin-stringer combinations;

g. Spar caps; and

h. Spar webs.

2.2.2 *Fuselage*

a. Circumferential frames and adjacent skin;

b. Door frames;

c. Pilot window posts;

d. Pressure bulkheads;

e. Skin and any single frame or stiffener element around a cutout;

f. Skin or skin splices, or both, under circumferential loads;

g. Skin or skin splices, or both, under fore-and-aft loads;

h. Skin around a cutout;

i. Skin and stiffener combinations under fore-and-aft loads; and

j. Window frames.

AMC 25.571(a), (b) and (e)

Courtesy Michael Borgman, Nov 2014 FAA workshop Bonded Repair Initiative

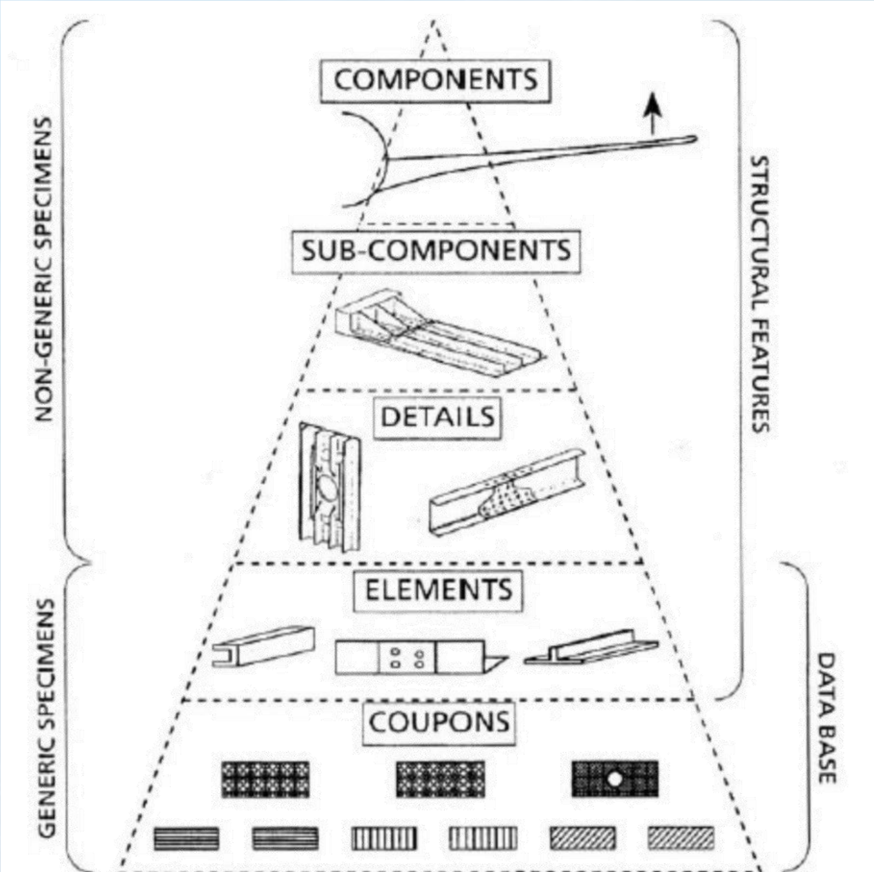
Damage Tolerance and Fatigue Evaluation of Structure

- The damage-tolerance evaluation of structure is intended to ensure that should serious fatigue, corrosion, or accidental damage [manufacturing defects] occur within the operational life of the aeroplane, the remaining structure can withstand reasonable loads without failure or excessive structural deformation until the damage is detected.

AMC 20-29 (AC 20-107B)
Building Block Test Protocol

Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

- Building block approach recommended for proof of structure mechanical testing (*when additional tests required*)



AMC 20-29 8.a.1.c
Categories of Damage

Courtesy Michael Borgman, Nov 2014 FAA workshop Bonded Repair Initiative

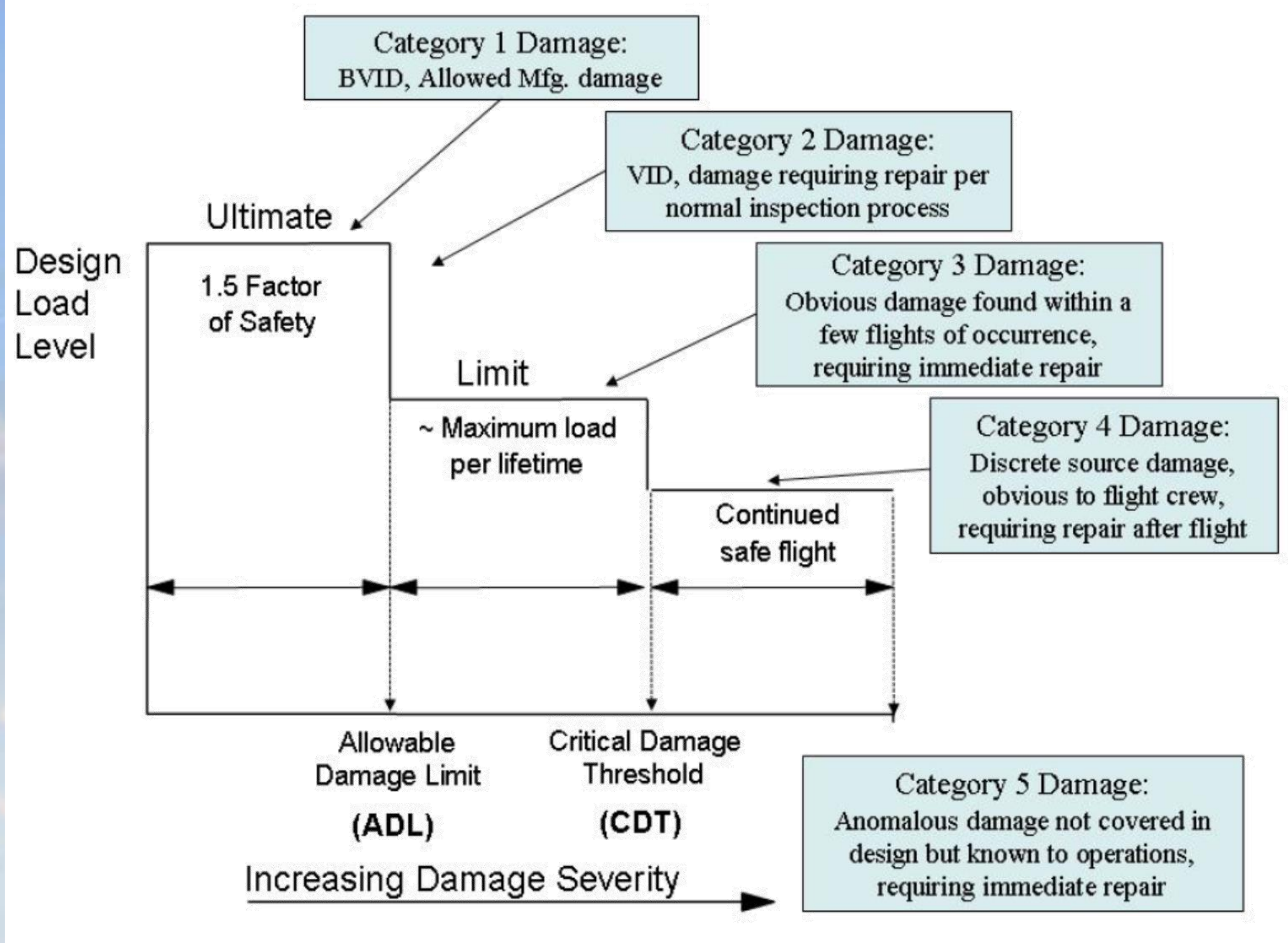


Figure 3 - Schematic diagram showing design load levels versus categories of damage severity.

AMC 20-29 (AC 20-107B)

6.b Design Considerations for Manufacturing Implementation

Courtesy Michael Borgman, Nov 2014 FAA workshop Bonded Repair Initiative

- Process specifications and manufacturing documentation for composite fab & assy.
- Facilities environment and cleanliness must be controlled to qualification validated level.
- Raw and ancillary materials controlled to specifications consistent with qualifications.
- Parts fabricated meet production tolerances validated in qualification, design, and proof tests.
- Key process considerations include:
  - (i) material handling and storage, (ii) laminate layup and bagging, (iii) mating part dimensional tolerance control, (iv) part cure (thermal management), (v) machining and assembly, (vi) cured part inspection and handling procedures, and (vii) technician training for specific material, processes, tooling and equipment.
- Substantiating data needed for all known defects, damage and anomalies allowed without rework.
  - Manufacturing records support identification and substantiation of known defects, damage and anomalies.
- New substantiating data is needed from new suppliers of parts previously certificated.
  - May be supported by manufacturing trials and quality assessments to ensure equivalent production and repeatability
  - Some destructive inspection of critical structural details is needed for manufacturing flaws not end item inspect-able.

Bonded Repair Size Limits Policy *Implications*

Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

- BRSL requires substantiation for two scenarios :
  1. Repair bond intact ("patch on") = Ultimate capable
  2. Repair bond failed ("patch off") = Limit Capable

		BRSL - implied substantiation requirements	
		1) Repair intact	2) Repair failed
Strength & Deformation	Limit	**X**	**X**
	Ultimate	**X**	**---**
Damage tolerance		**X**	**Y**
Durability		**X**	**Y**
Environmental resilience		**X**	**Y**

X = basis airframe TC requirements

Y = requirements defined during **repair** substantiation and approval process

Bonded Repair Substantiation Checklist *(Regulations)*

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Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

SUBSTANTIATION CHECKLIST **CS 25.XXX Requirement**		**Repair Bond**	
		Intact **(Ultimate Load Capable)**	**Failed** **(Limit Load Capable)**
25.305	**STRENGTH AND DEFORMATION**		
	Safe Operation at ***Limit*** *Load* (deformations okay)		
	Ultimate *Load* capability		
25.307	**PROOF OF STRUCTURE**		
	Each critical load case considered		
	Analysis methods proven to be valid		
25.571	**DAMAGE TOLERANCE AND FATIGUE EVALUATION**		
	No catastrophic failure due to fatigue (progressive damage)		
	No catastrophic failure due to corrosion		
	Manufacturing defects considered		
	Accidental damage considered		
	Load and environment spectra considered		
25.603	**MATERIALS**		
	Process performed in accord with approved documented specifications		---
25.605	**FABRICATION METHODS**		
	Process proven to yield strength/stiffness assumed in design		---
25.613	**MATERIAL DESIGN VALUES**		
	Strength assessments based design values with valid statistical basis		
25.619	**SPECIAL FACTORS**		
	Basis exists for special factors applied		

Bonded Repair Substantiation Checklist (Guidance)

Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

SUBSTANTIATION CHECKLIST **Guidance**	**Repair Bond**	
	Intact (Ultimate Load Capable)	**Failed** (Limit Load Capable)
CS-25 Book 2 AMC 25.307		
Proof of structure by analysis supported by existing test evidence, or		
Proof of structure by analysis supported by new test evidence, or		
Proof of structure by Test Only		
Limitations of stress analysis method understood		
Conservative stress analysis assumptions used to compensate for limited test evidence		
CS-25 Book 2 AMC 25.571		
If repair bond fails residual structure can withstand reasonable loads until failure detected		
Part is *Principal Structural Element*		
Bond failure detection strategy and corresponding *special inspections* and intervals defined		
CS-25 Book 2 AMC 25.613		
Repair M&P aligns with M&P used in design value development (*or equivalency established*)		
Mechanical test specimens conform to universally accepted standard		
Effects of temperature and moisture taken into account in design values development		
AC 21-26A		
"Quality System" employed in repair materials and processes controls		
Inspection standards exist for NDI acceptance tests		
Inspection standards exist for DI acceptance tests		
inspection standards exist for visual inspections		
Geometric inspection performed to confirm compliance with engineering requirements		
AMC 20-29		
All Materials & Processes qualified by manufacturing trials and appropriate testing		
Surface preparation performed in accord with process qualification or approved data		
Mechanical tests for proof of structure performed at appropriate levels of building block		
Bond failure detection strategy and corresponding *special inspection* intervals and protocol defined		
Bonded Repair Size Limits Policy Memo		
Repair size no larger than size allowing LIMIT LOAD residual strength with repair failed within constraints of arresting design features		

Proposed Tests

Summary of Pyramid Tests:

Courtesy Michael Borgman,
Nov 2014 FAA workshop
Bonded Repair Initiative

6: Major Test: **None**

5: Component: **None**

4: Sub-Component
Six stringer panel, repeated compression load and residual strength (with/without damage)

3: Detail: **None**

2: Element: Scarf Joints
All environmental conditions, static strength, strength after impact, strength after cyclic load

1: Coupon
1) Repair laminate design values, 2) Combined laminate design values

Summary, The Challenge of Primary Structure and necessary Repair Substantition

- **Examples of capable and responsible repair techniques and methods that prove to be restorative to the original mission have been examined throughout this workshop. It is also impossible to ignore the variation that has been witnessed from the 2004 CACRC Round Robin test effort, to the 2014 test effort of the same ilk (different coupon types), as well as examples of repairs in the fleet that simply did not work.**

- **One thing that can be concluded, is that the components of repeated Large Area repair efforts that have been proven successful, followed techniques more common to complying to FARs 23,24,25,26, 33, 34 or 36, than to MRO efforts that comply to FARs 43 and 145. Observation only.**

- **For Primary Structure applications that one day can be universally accepted for composite repair techniques, it may have to be recognized that repair methods and techniques more closely resembling Production Processes, are a necessary avenue to gaining wide spread repair method, materials, and technique acceptance.**

- **There has been some very good work done to lay the ground work for how to perform potential Primary Structure composite repairs, however, a great deal of substantiation testing remains for all. It looks like a good game plan, we should stick with it, follow it, and improve it where needed.**

- **Some innovation in surface preparation, newer, higher strength (and strain) adhesive formulations, and exploration into techniques that have worked on other structure to see if they apply to Primary Structure, would assist in gaining more traction for future PSE composite repair "acceptance."**

- **It would be very helpful, and truly desired to arrive at a unified position of what constitutes "substantiation", and methods to go about achieving it.**

- **Training is an important facet to continue to explore. The author feels "practice" as part of a training or certifying event is also a key factor to actually being able to have a controlled repair process.**

- **The need to repair commercial transport composite Primary Structure will not go away. The need to repair and return to service damage sizes that are greater than those identified by Bonded Repair Size Limits will also exist. Without continued efforts to research and find solutions of this nature, the future maintenance challenges of all composite aircraft may deem that material choice "negative" from a business or dispatch perspective. We need to continue to find a way to repair, capably, Primary Structure.**

John M. Welch