"Bonded Repair Service Provider - Service History and Substantiation"

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

Bombardier Aerospace, Montreal, Quebec, Canada, September 15, 2015

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Global Customer Supply and Support

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September 15, 2015

Spirit Worldwide Operations

Spirit Aerosystems Is The World's Largest Independent Supplier Of Commercial Airplane Assemblies And Components.

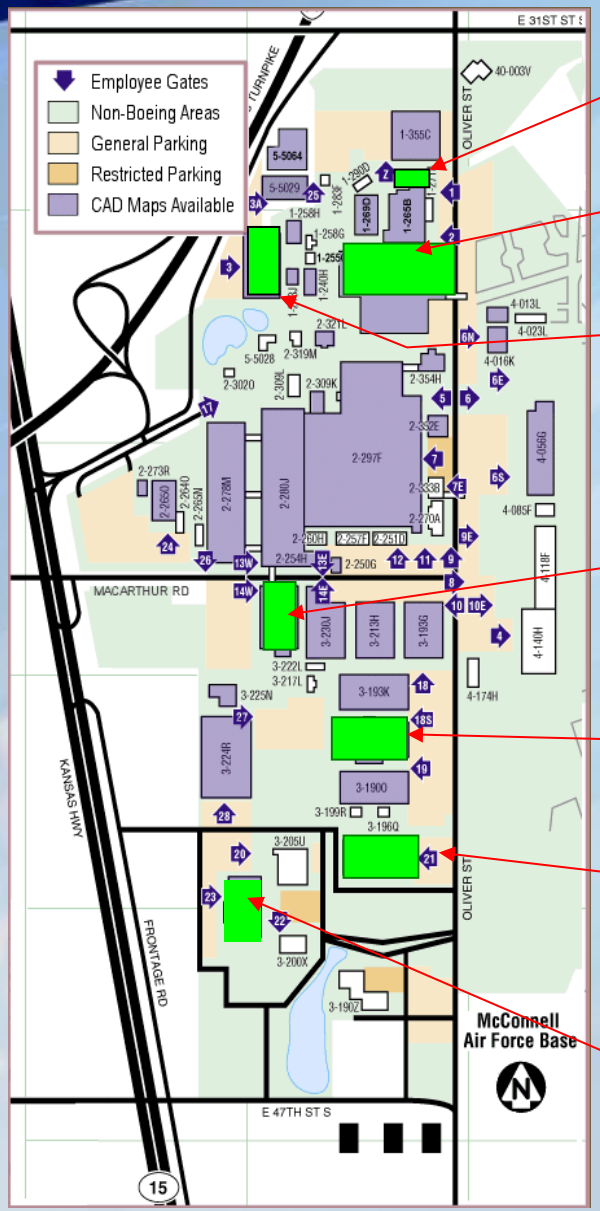
- ~ 14,000 Employees
- ~1,900 Engineering Resources Available
- ~ $6.1B Revenue
- ~ 14.5 Million Square Feet

Spirit's Global Footprint Continues to Expand

PS&S Facilities Footprint

Mission:

To be the preferred Propulsion Hardware and Services provider in the world



Acoustic Lab

Strut / Nacelle Assembly

MRO/Repair Center Strut Assembly

Composite Fabrication Nacelle components

Strut/Nacelle and Machining Fabrication

737 Nacelle Thrust Reverser Composite Fab and Assembly

Engineering Test Facility

Vision:

Innovative People, Processes, and Technologies focused on providing the best value propulsion products to our customers and stakeholders.

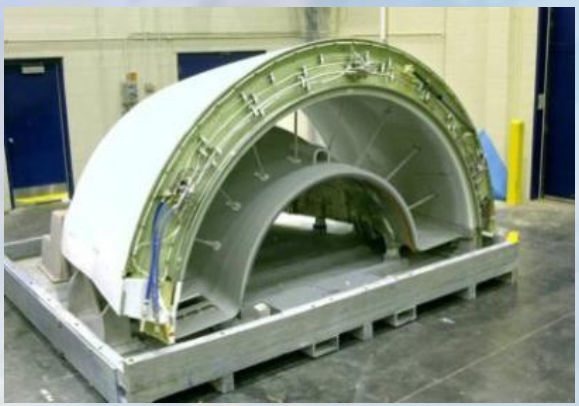
Strategy:

Provide customers with a fully integrated Propulsion Structures & Systems package that can be delivered directly to the airplane.

PS&S Total = 1.2M s.f. and 1,900 employees

Composite Fabrication

- ✓Largest quantity of autoclaves in one location
- ✓Extensive Design/Testing capabilities
- ✓Composite and noise technology patents
- ✓Proprietary noise abatement technology
- ✓Tooling innovations
- ✓Supplier partnering relationships
- ✓Highly skilled factory workforce with co-located support



Fleet Support

FAA certified repair station (#Z6WR336Y)
provides on-site support

- ✓ Repair and overhaul
- ✓ Routine maintenance
- ✓ Warranty administration
- ✓ Other technical services

Ability to supply directly to airlines

Over 20,000 square feet, including a clean room for composite repair

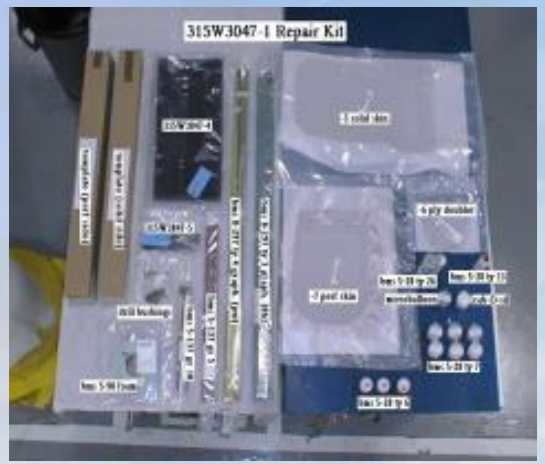
Creating Another Repair Kit

- In Preparation to Create a Repeated Use Repair Kit for SB1079/AD2012-05-02 we employed the following:
- Experience from daily production and MRO repairs has shown that repair methods can closely match production processes and production repairs.
- Experiences from Fleet data on kitted repair performed in the field, and methods used there have shown consistent positive, predicted results, for performance.
- In an effort to make our MRO more efficient we examined repairs currently being done on Propulsion hardware, and those that were forecast.
- We learned:
  - Almost all our repairs were done individually, no two repairs matched geometrically.
  - A great deal of time was involved in repair preparation, ply design, ply cutting, nesting, lay-up, etc.
  - We discovered a great deal of our composite repair was being performed to a specific set of Service Bulletins, but all the approvals were “individual”
  - Examined the need for a standardized repair method
  - Referenced previous experience from prior successful repair patches/kits,

Examples of Practiced Repair Kits – Past Experience

Thrust Reverser Inner Wall Damage from Start Bleed Duct

Circa 1997



- Bleed Valve Failure Repair Kit.
- All necessary components to perform repair
- Accompanied by detail repair instructions
- Maintenance center estimated 30-45 days for effort. Accomplished repair on 3 units - took 5, 4, and 3 days respectively.
- Provided 8110, carrier provided 8130.

Consolidated Repair Patch being placed

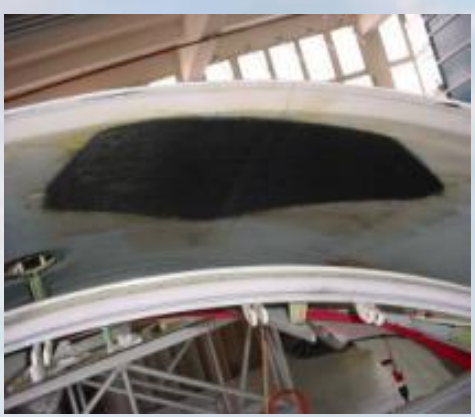
Restored Perforations

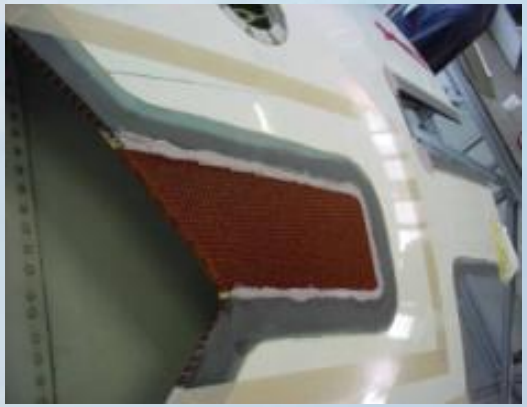
Examples of Practiced Repair Kits – Past Experience

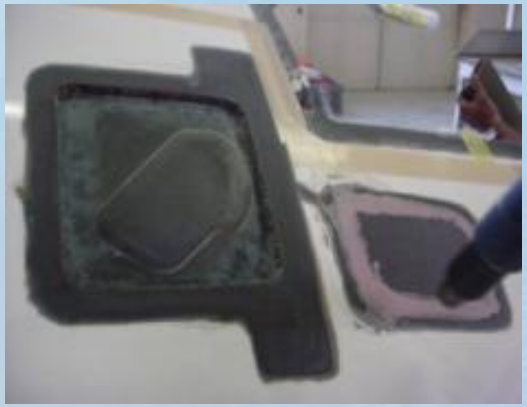
Large Area Trans-Sleeve Repair

Circa 2001

- Trans-Sleeve Repair Kit, for foreign carrier
- All necessary components to perform repair
- Accompanied by detail repair instructions
- Hardware had been out of commission for over 1 year.
- Accomplished repair on 1 unit – took 10 days.
- Provided 8110, carrier provided 8130. Wrote document that detailed repair with margins and conclusions.







Through Penetration | Several Stages of Core Repair | Innovative "Cavity" Repair | Perforate Restored

37,000 cycles, 82,000 hours

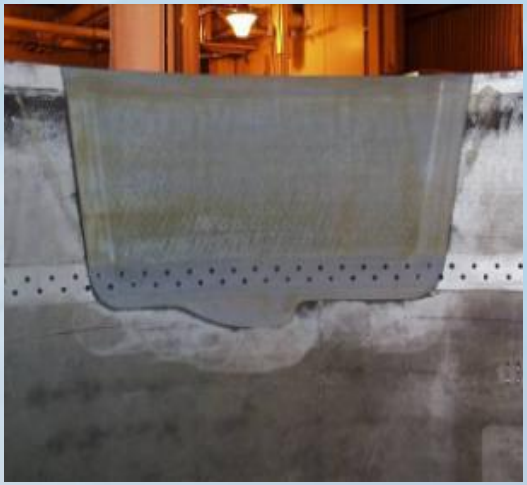
Examples of Practiced Repair Kits – Past Experience

Large Area Trans-Sleeve Repair

Solid Side Replaced

Circa 2002

Core Replaced



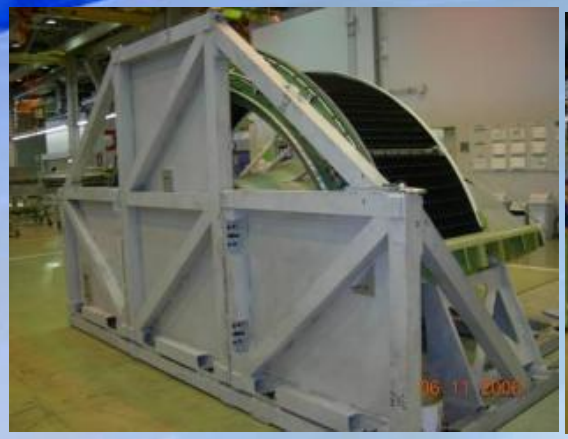
Perforate Restored

17,000 cycles, 52,000 hours

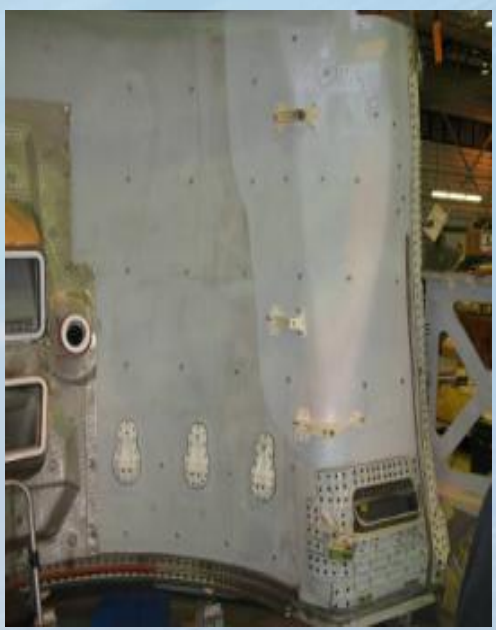
Examples of Practiced Repair Kits – Past Experience

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)

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

Placement of consolidated repair kit, onto structure

Smoothing kit into sanded recess, tool located and template aligned

Result – Kit is ready to bag and cure – total time involved in placement --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

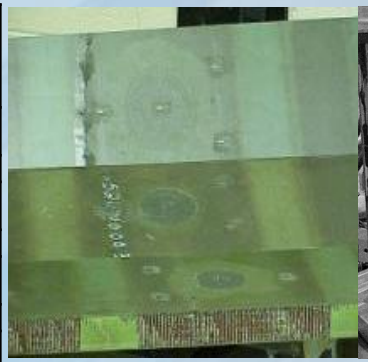
Example Test Matrix: Tension, Static, RT

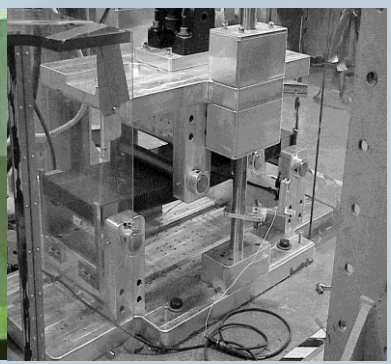
Tension

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

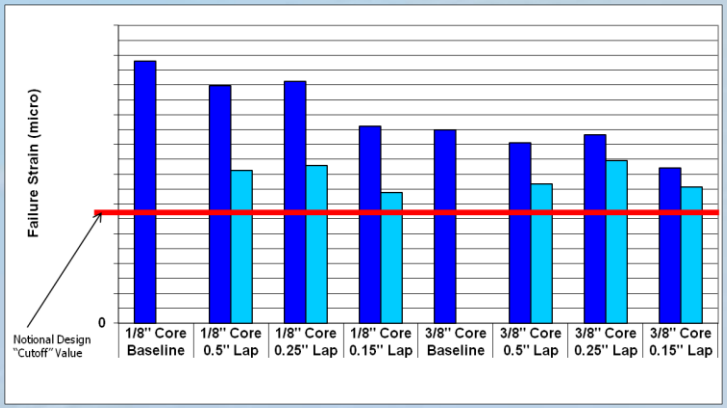
Note: Current Validation Matrix coupon count is 278 coupons





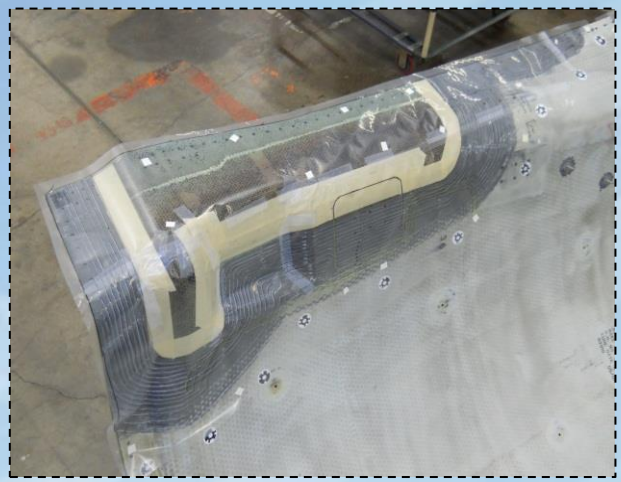
Large Beam Bending

Test Results



- Decided to employ prior experience and detailed part/product knowledge to address a consistent, designed, standardized repair method, and materials.
- Our MRO targeted SB1079,1085 etc, now wrapped up into AD2012-05-02
- Spirit has funded (continues) a design, tooling, and fabrication effort to create standardized repair methods to address AD2012-05-02
- We created:
  - A designed repair kit, and supporting tooling such as ply orientation tapes, tooling, cloth kits, nc-tapes, and laser templates for location and lay-up
  - A resultant repair kit, all structural carbon plies, adhesive, etc, that complies with AD2012-05-02 – **i.e. Autoclave cured**.
  - A resultant repair kit, all structural carbon plies, adhesive, etc, that meets or exceeds the requirements of AD2012-05-02, but is performed **out of autoclave.**
  - Testing data, complied, that supports the structural analysis and configurations described above.
  - A repair method, documented, that if followed like a process specification, will provide compliance to AD2012-05-02 (autoclave) and out of autoclave via AMOC. The repair method includes the NDI method.

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

Example of SB/AD Repair Kit

Tooling for the AD2012-05-02 repair kit

- -Fits production processes
- -Removes any doubt about direct compliance match to original structure
- -Faducial supports laser templates, repeated nc location, etc.
- -Cloth kits cut with NC tapes support the Autoclave version
- -Tool supports lay-up and consolidation for Out of Autoclave version

Currently working to Make a SB/AD Repair Kit

Damage to T/R inner fixed structure detailed In SB 1079, now AD2012-05-02

Requires large area of repair

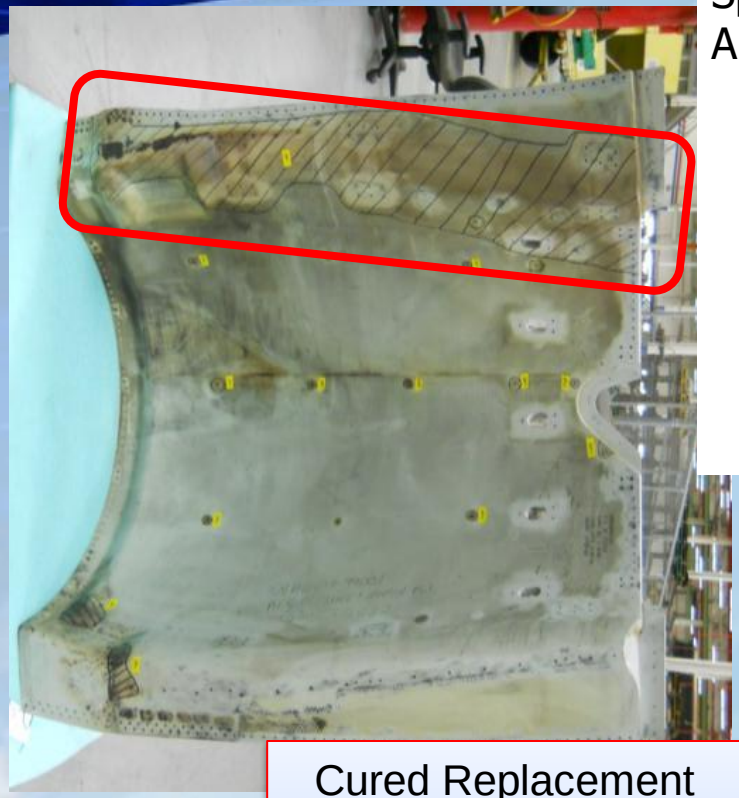
Currently each panel is individually repaired – no Two panels have been identically repaired.

There is a large population of panels that will be required to comply.

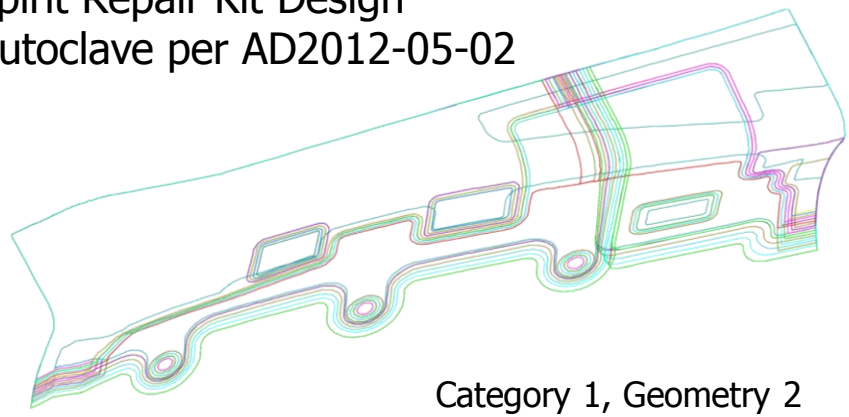
Spirit funded a program to design a repair kit that will be applied to all inner walls of this type.

Design of repair kit is now 100% completed.

Spirit plans to make repair kit available.

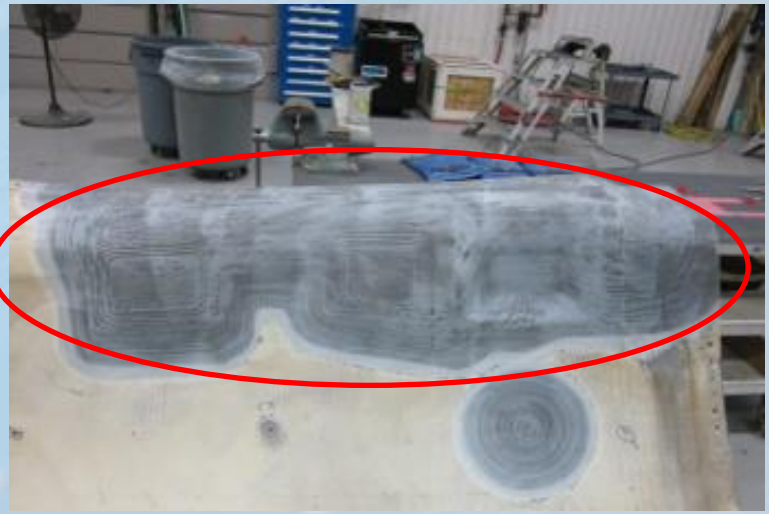


Spirit Repair Kit Design
Autoclave per AD2012-05-02



Category 1, Geometry 2

Cured Replacement Composite Material Ready for NDI

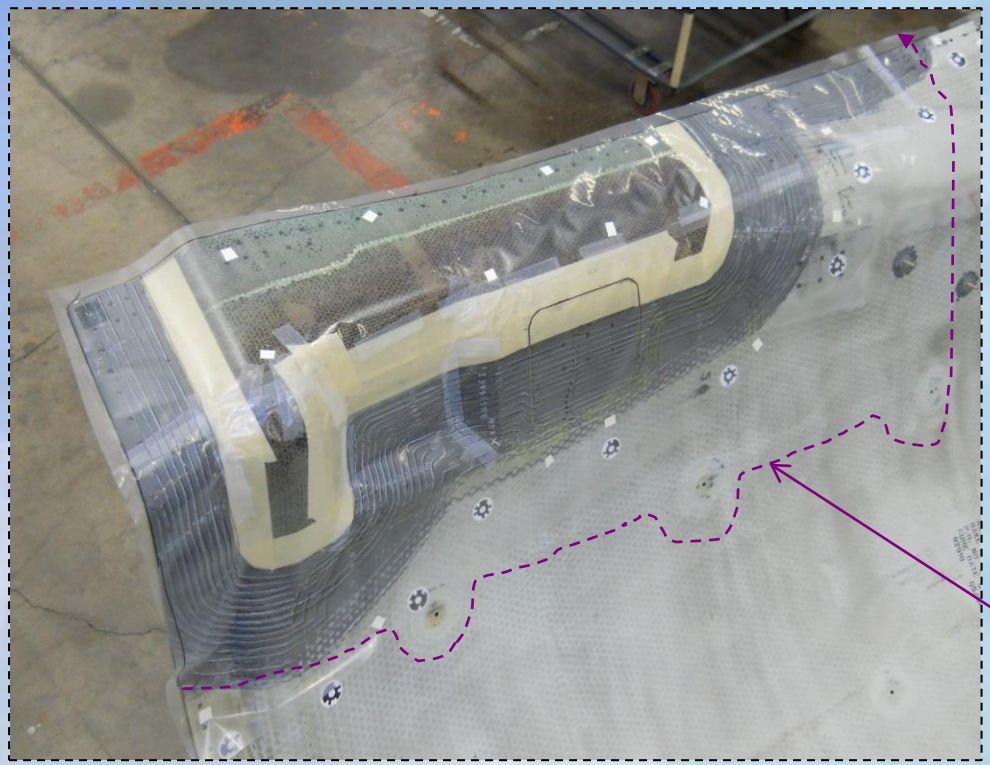


Repair Size = Hours on wing

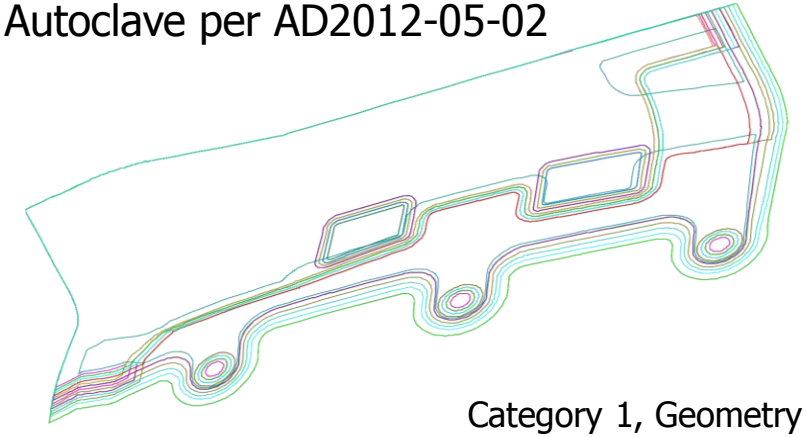
There are two basic geometries, and two categories of repair:
- Geometry 1 – just forward of #2 compression pad, aft to trailing edge, Geometry 2 – entire upper bifurcation fwd-aft
- Category 1 – Autoclave repair, Category 2 – Out of Autoclave repair

Number 1 Goal – Supply enough data to convince OEM and regulators we can perform this Standardized Repair outside of autoclave.

Currently working to Make a SB/AD Repair Kit



Spirit Repair Kit Design
Autoclave per AD2012-05-02



Category 1, Geometry 2

Approximate Boundary of Cat 1, Geom2
Spirit Repair Kit as applied to the structure

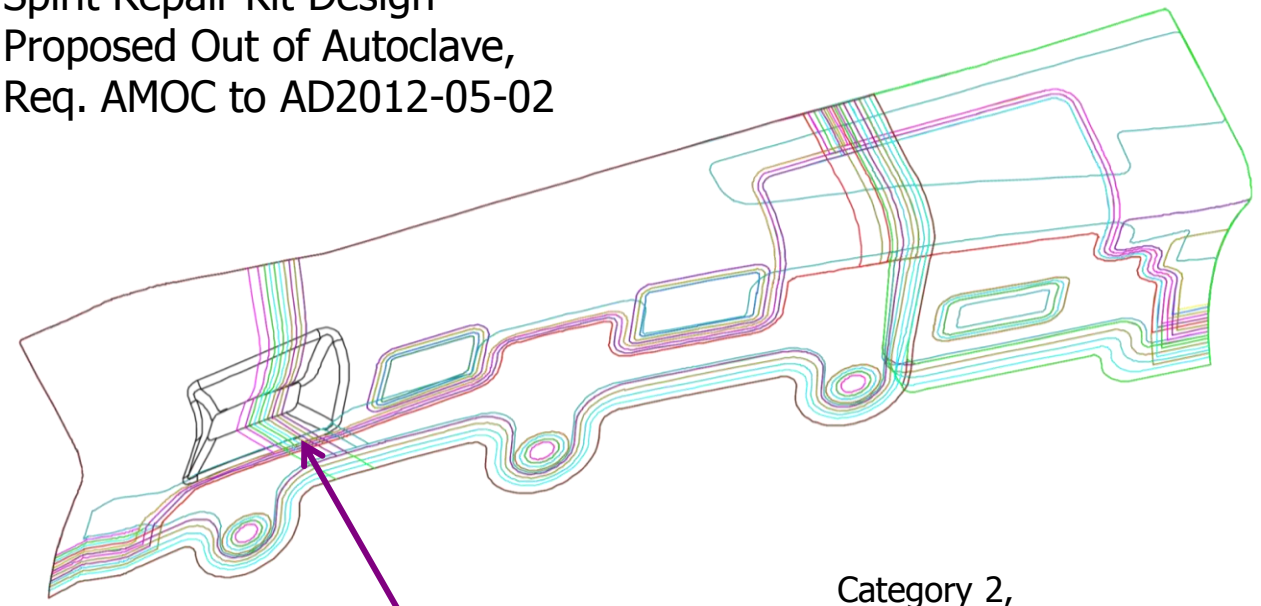
Repair Size = Hours on wing

There are two basic geometries, and two categories of repair:
- Geometry 1 – just forward of #2 compression pad, aft to trailing edge, Geometry 2 – entire upper bifurcation fwd-aft
- Category 1 – Autoclave repair, Category 2 – Out of Autoclave repair

Number 1 Goal – Supply enough data to convince OEM and regulators we can perform this Standardized Repair outside of autoclave.

Currently working to Make a SB/AD Repair Kit

Spirit Repair Kit Design
Proposed Out of Autoclave,
Req. AMOC to AD2012-05-02



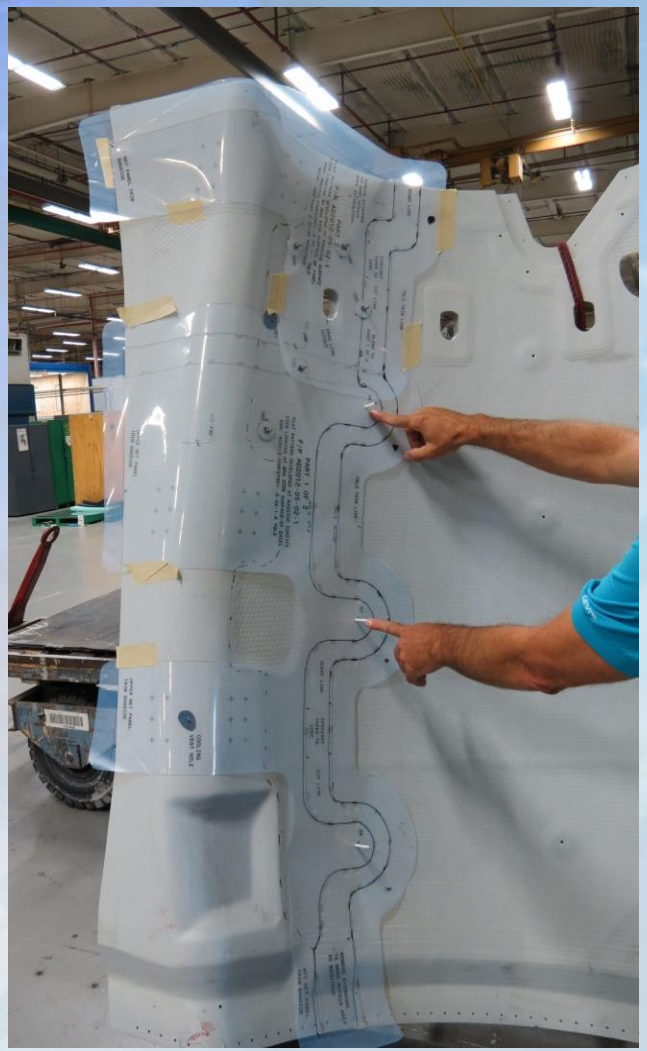
Category 2,
Geometry 1 and 2

Note: Additional Designed Splice to
Ensure Heat Blanket and Ply Kit Contour Compliance
Would be cured in "sections" as done previously

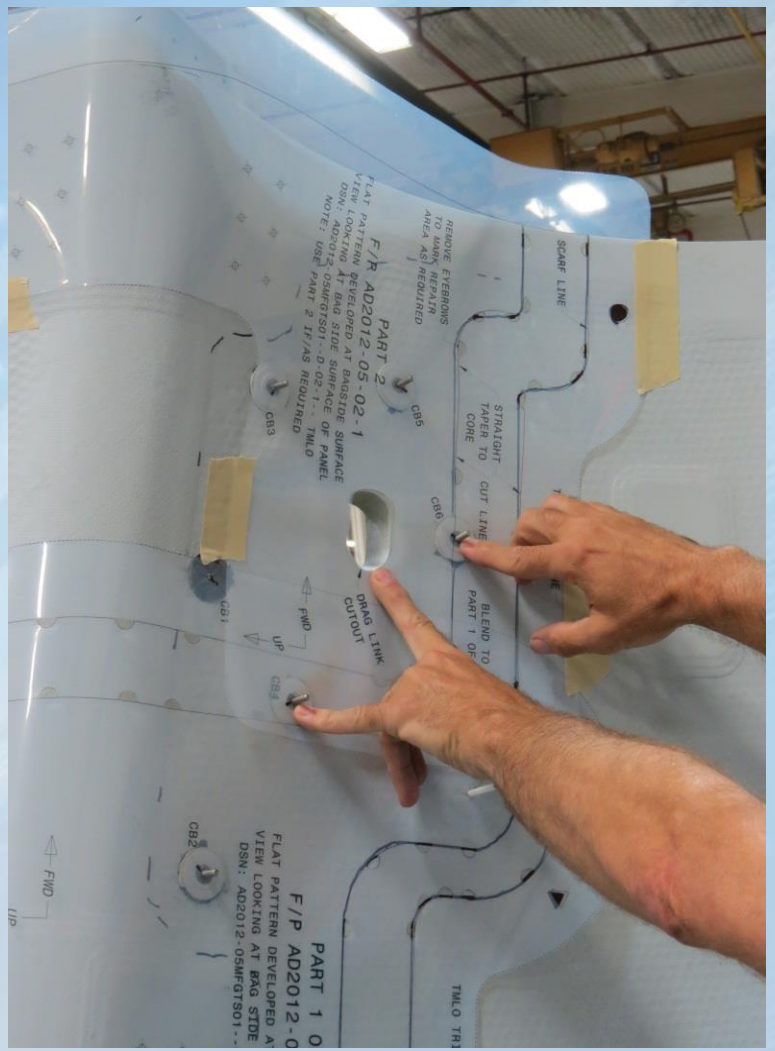
There are two basic geometries, and two categories of repair:
- Geometry 1 – just forward of #2 compression pad, aft to trailing edge, Geometry 2 – entire upper bifurcation fwd-aft
- Category 1 – Autoclave repair, Category 2 – Out of Autoclave repair

Number 1 Goal – Supply enough data to convince OEM and regulators we can perform this Standardized Repair outside of autoclave.

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



Spirit Provides Tools
And Templates



Sanding Template
Indexes to panel Features

Marked, and Ready
For Material Removal

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

Taper Sanding Removal

Ready for 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

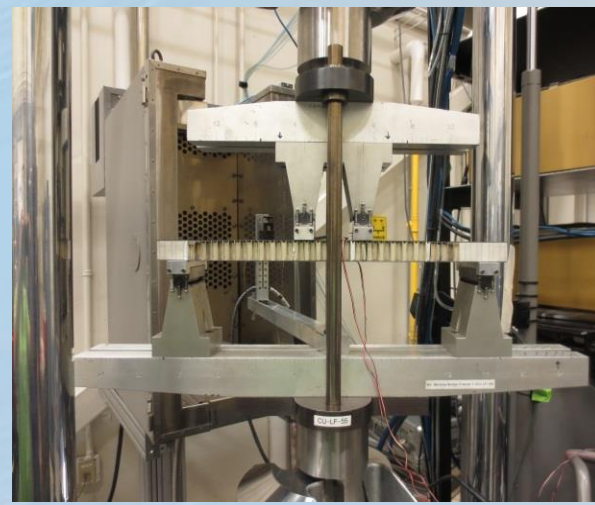
Tension – Sandwich, HD

Flex – Sandwich, L

Tension - Sandwich

Pin Bearing

Flat-Wise Tension



Flex – Sandwich, LD

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

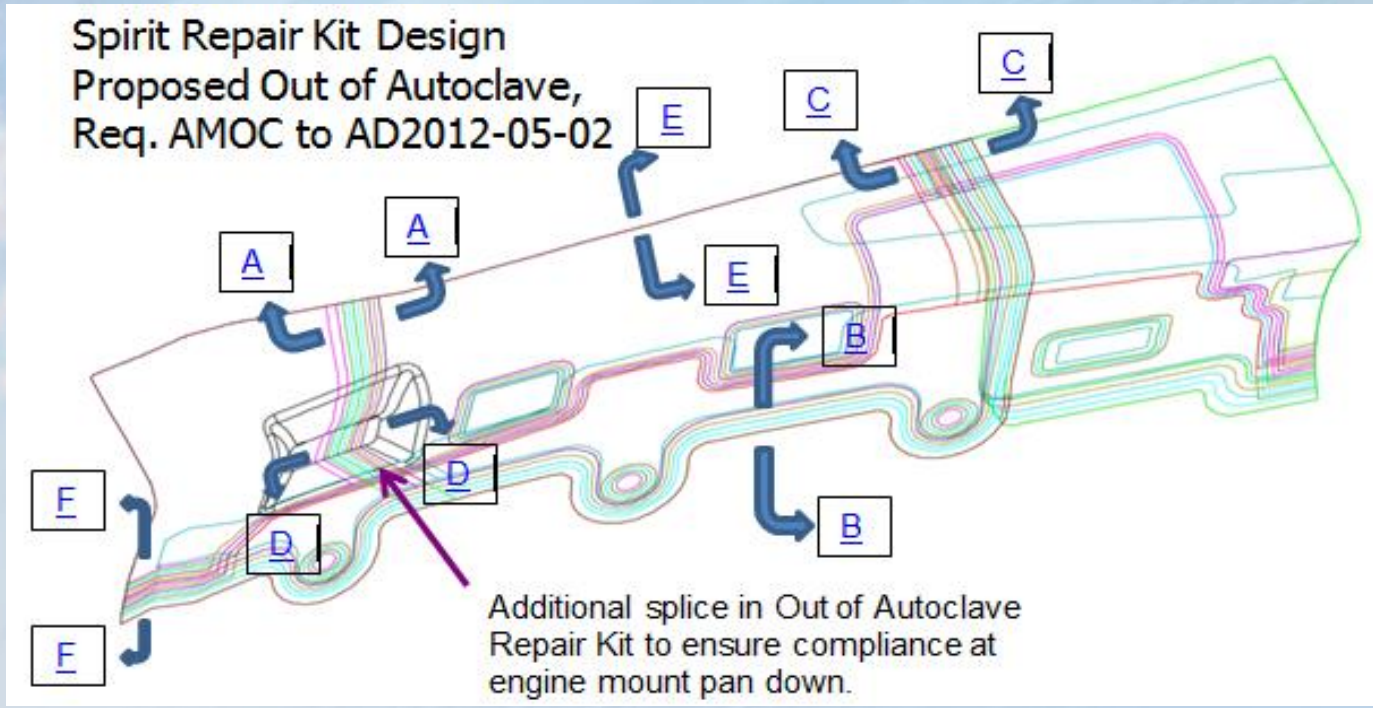
Testing Strategy as defined in MAA7-71277-1, Rev C

Two Basic Families of Coupons:

Baseline – Autoclave cured per applicable production process specification

Repaired – Out of Autoclave cured with Spirit Proprietary process

- Defined five families of Repair Types, A,B,C,D,E,F



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

Tension Testing: (ASTM D3039)

Baseline Sandwich Structure:

2 types, High Density Core, Thick Facing (BL-1), Low Density Core, Thin Facing (BL-2)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Baseline Laminate Structure: (BL-3)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Sandwich Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

3 types, High Density Core, Thick Facing (Repair Type A and C), Low Density Core, Thin Facing, (Repair Type B)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Laminate Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

2 types, Repair Types D and F the differences being the substrates repair plies were bonded to

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Edge Compression Testing: (ASTM C364)

Baseline Sandwich Structure:

2 types, High Density Core, Thick Facing (BL-1), Low Density Core, Thin Facing (BL-2)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Baseline Laminate Structure: (BL-3)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Sandwich Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

3 types, High Density Core, Thick Facing (Repair Type A and C), Low Density Core, Thin Facing (Repair Type B)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Laminate Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

2 types, Repair Types D and F the differences being the substrates repair plies were bonded to

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Flex Beam (Compression) Testing: (ASTM D7249)

Baseline Sandwich Structure:

2 types, High Density Core, Thick Facing (BL-1), Low Density Core, Thin Facing (BL-2)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Sandwich Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

3 types, High Density Core, Thick Facing (Repair Type A and C), Low Density Core, Thin Facing Repair (Type B)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

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

Flex Beam (Compression) Open-Hole: (ASTM D7249)

Baseline Sandwich Structure:(Cured in Autoclave, Production Process)

High Density Core, Thick Facing (BL-1))

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Sandwich Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

High Density Core, Thick Facing (Repair Type E)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Pin Bearing Testing: (ASTM D5961)

Baseline Sandwich Structure: (Cured in Autoclave, Production Process)

High Density Core, Thick Facing (BL-1)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Repaired Sandwich Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

High Density Core, Thick Facing (Repair Type E)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

Flat-Wise Tension Testing: (ASTM C297)

Baseline Sandwich Structure: (Cured in Autoclave, Production Process)

Low Density Core, Thin Facing (BL-2)

Tested at RT and 300F, after a minimum of 30 days humidity conditioning

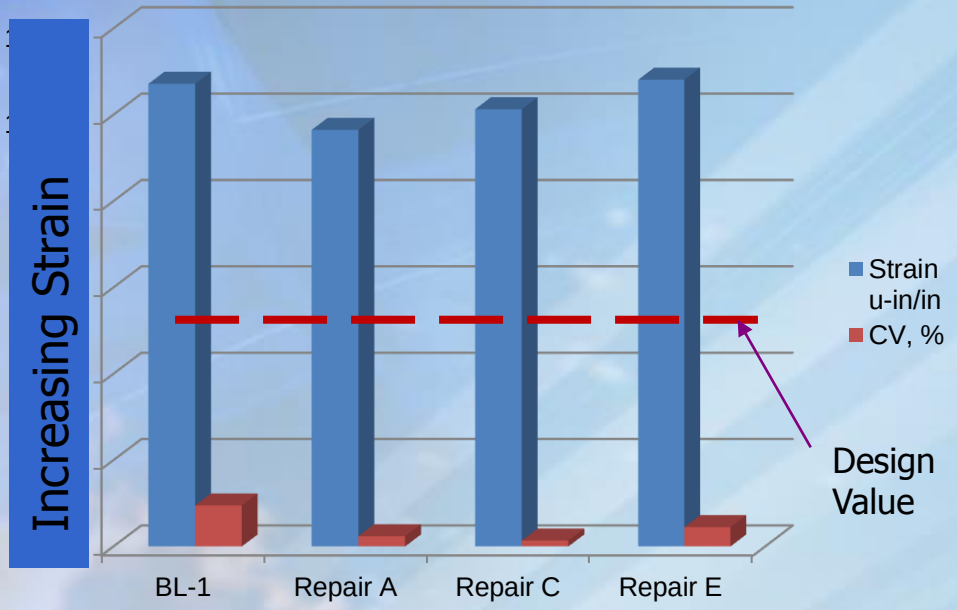
Repaired Sandwich Structure: (Prepared by Spirit Proprietary process, cured under vacuum using heat blanket)

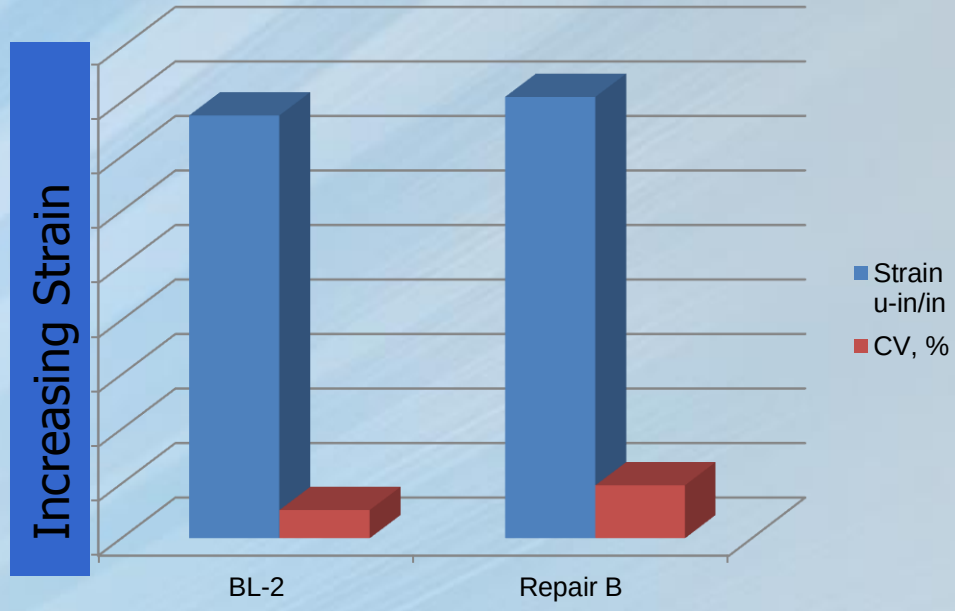
Low Density Core, Thin Facing Repair (Type B)

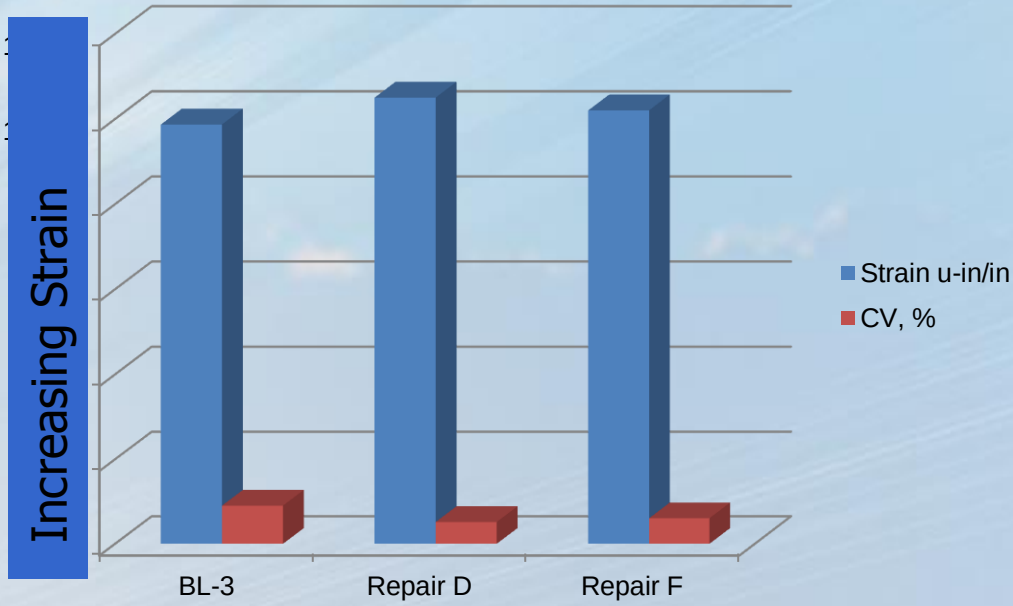
Tested at RT and 300F, after a minimum of 30 days humidity conditioning

344 Total Coupons, 3 Baseline Families, 5 Repair Configurations, 6 Loading Types, Room Temp And Conditioned Elevated Temp, to Compare Autoclave Cured to OoA cured Repair Elements

Test Results – Tension, for a SB/AD Repair Kit

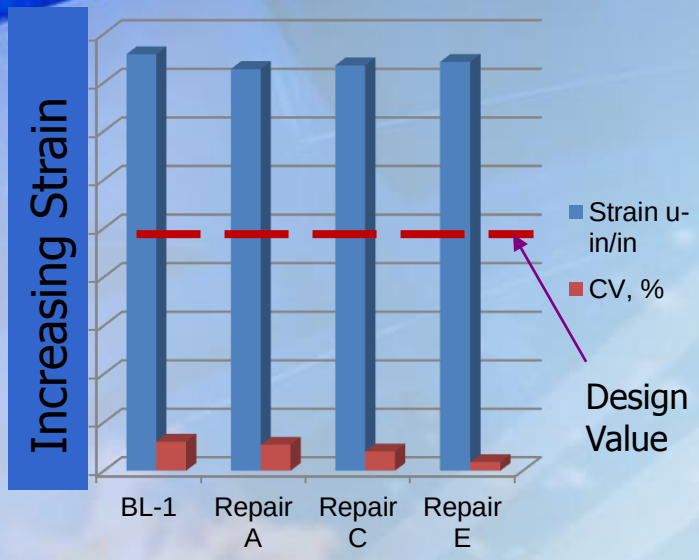


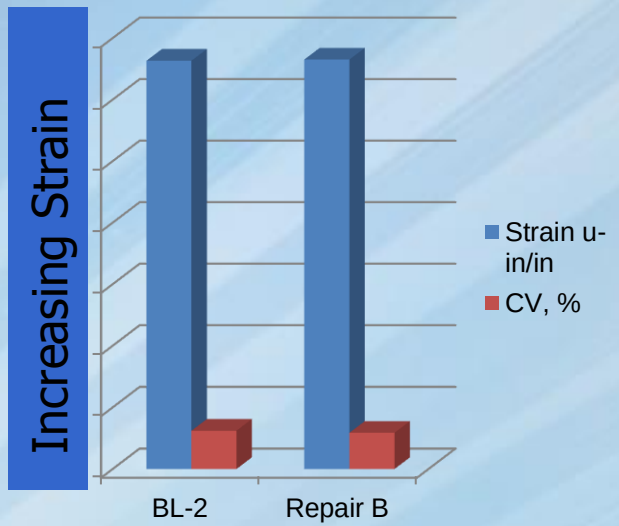


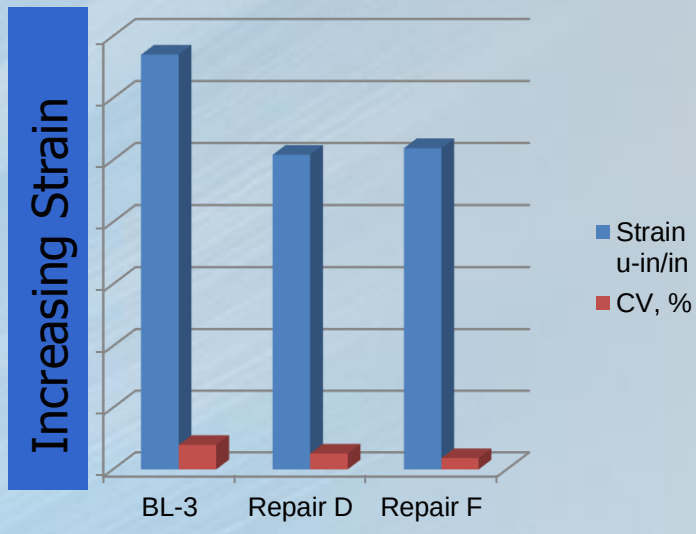


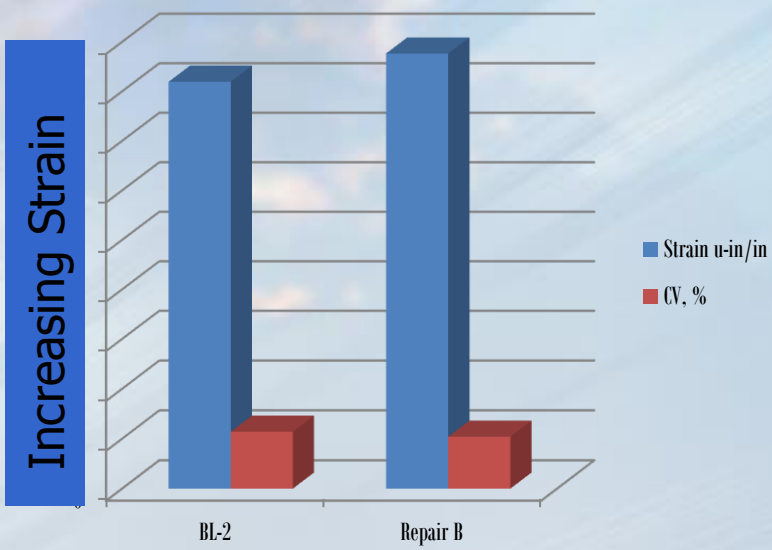
Test Results – Compression, for a SB/AD Repair Kit

Edgewise Compression

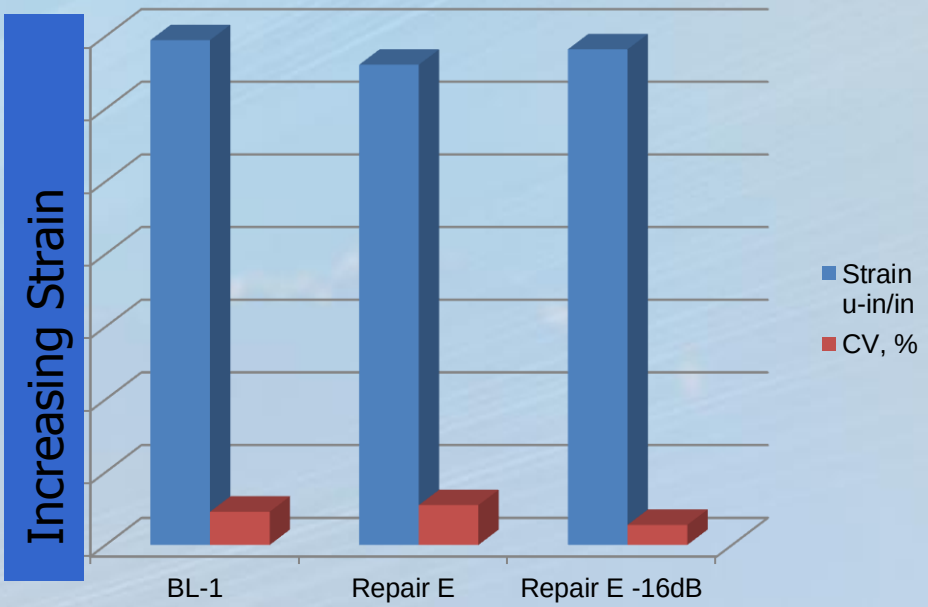






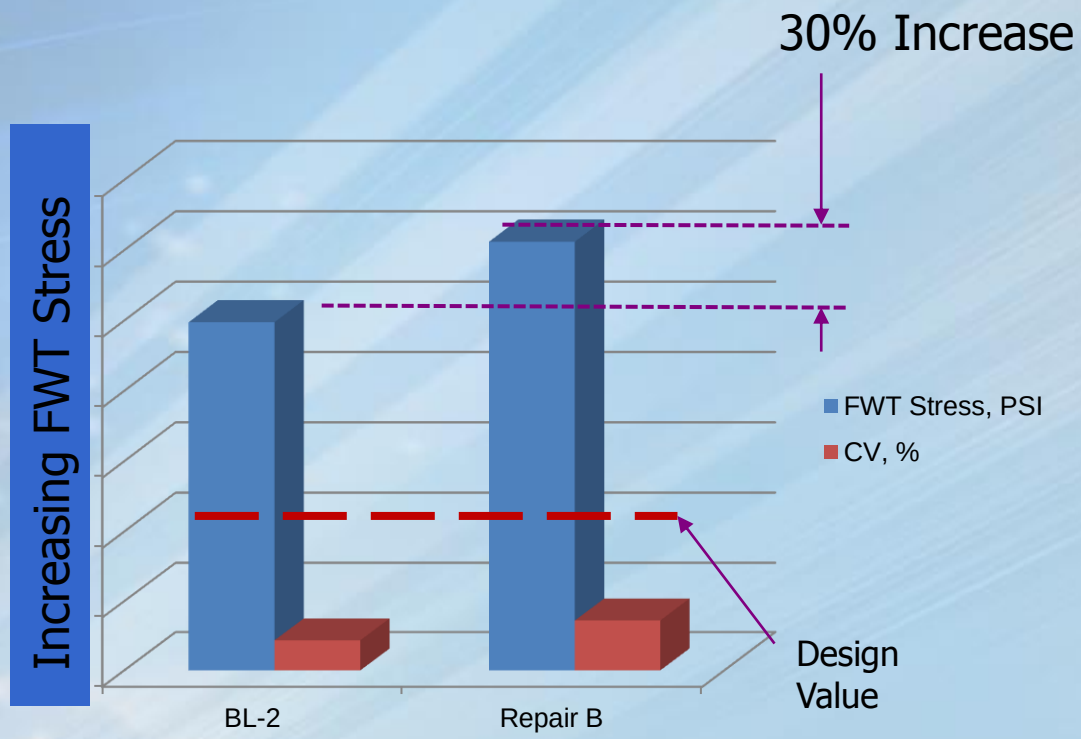


Flex Beam Compression



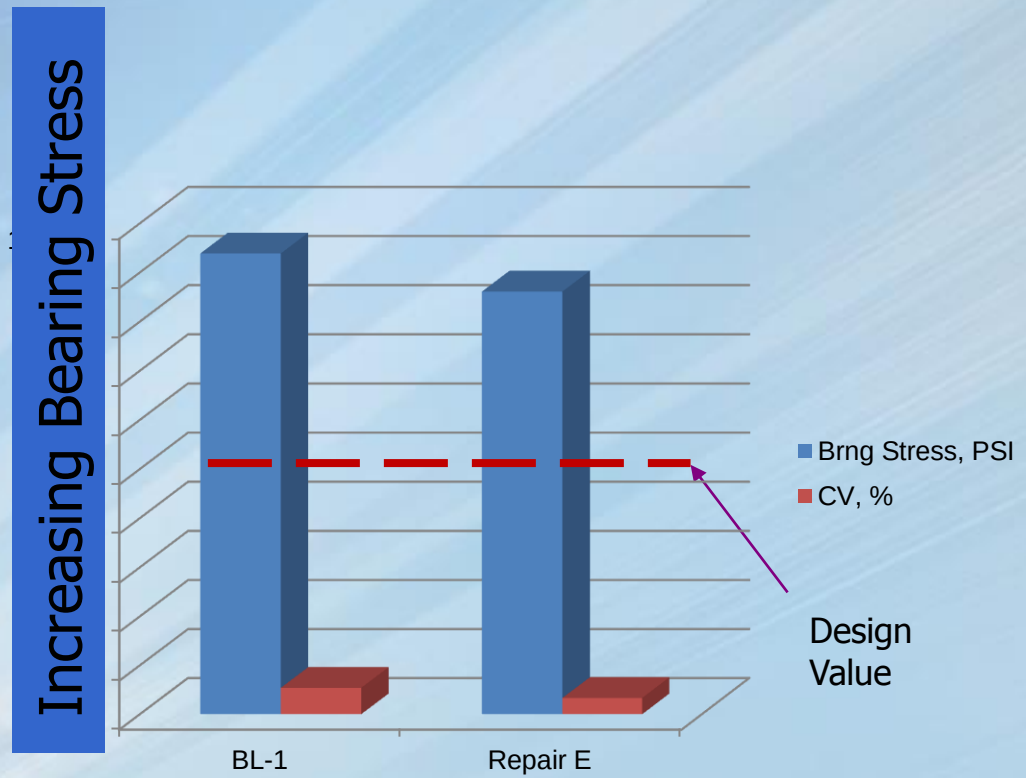
Flex Beam Compression – Open Hole

Test Results – Flat-wise Tension, for a SB/AD Repair Kit



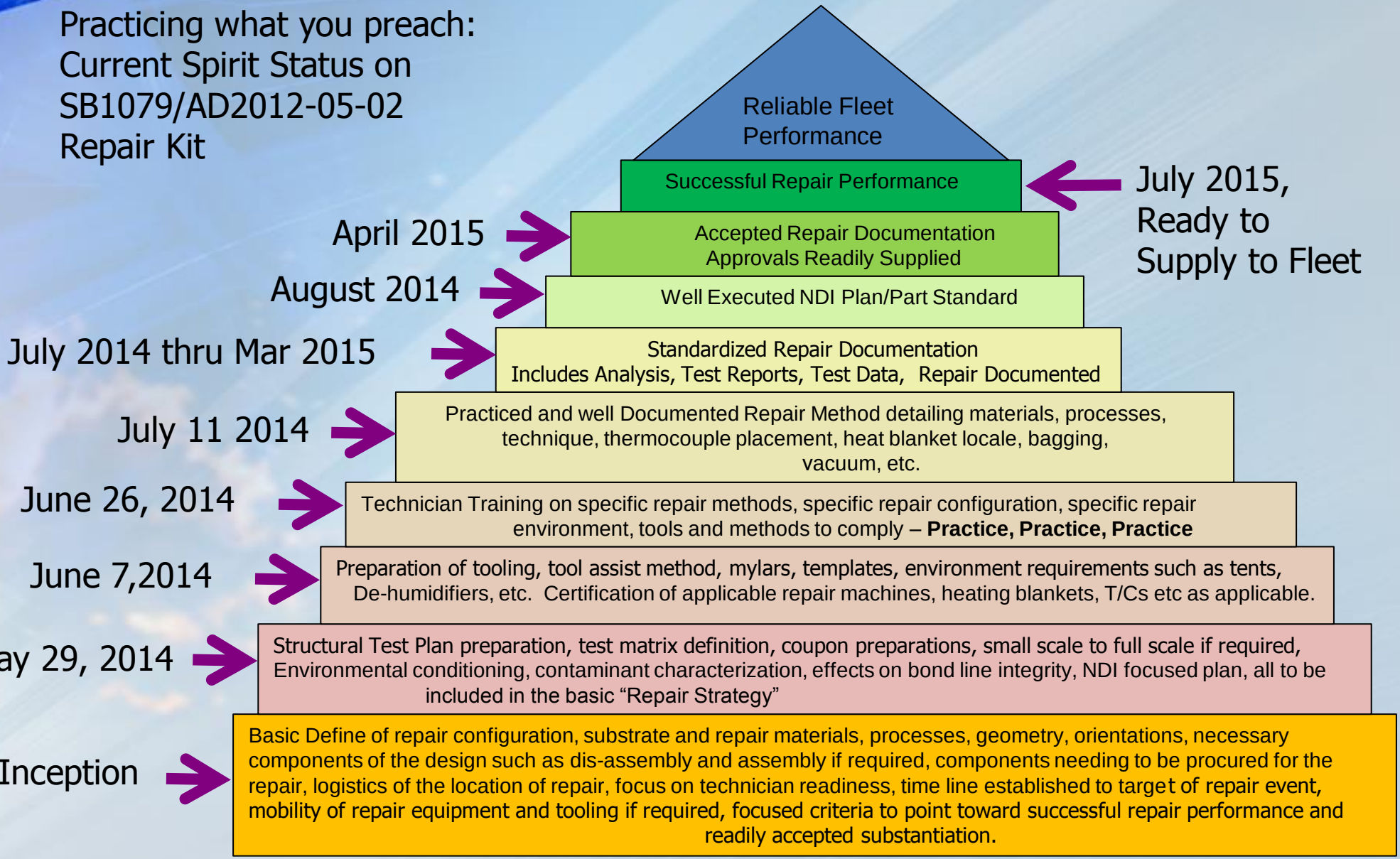
The author attributes this structural strength increase to the substantially greater consolidation and air evacuation associated with the group of "high pressure" de-bulks in the Spirit kit preparation process.

Test Results – Pin Bearing, for a SB/AD Repair Kit



Repair Road Map-Pyramid to Successful Repairs

Practicing what you preach:
Current Spirit Status on
SB1079/AD2012-05-02
Repair Kit



Kitted Repairs for the MRO and Aftermarket

- **Referencing experiences from a wide variety of repairs performed in the fleet and inside our own MRO, we have learned there is the ability to repair and restore the original mission intent of the hardware. This reliability has been proven over a large group of panel types, designs, and damage events, with significant fleet time on repairs (50,000 + hours per repair, total cumulative flight time in the fleet, 1.5 Million hours).**

- **Using this experience, we wanted to make our MRO more efficient. We analyzed a large population of a repeated damage sites that is corrected by a specific Airworthiness Directive. We found we could create a designed, repeatable, nearly identical, repair configuration and technique, using the exact OEM materials.**

- **This thrust reverser inner wall designed repair has two fundamental facets:**
  1)Autoclave processes using OEM materials, pre-kitted to the exact geometry of the needed repair, directly compliant to the AD2012-05-02.
  2)An Out of Autoclave process using OEM materials, pre-kitted to the exact geometry of the needed repair, pre-oriented and consolidated, employing designed tooling for exact placement, supported by validation testing, and eventually accepted via an Alternate Means of Compliance.

- **Validation Testing has shown that Out of Autoclave methods, when combined with Spirit Proprietary kit preparation, is equally effective to autoclave supported repairs, in terms of structural restoration. While the goal was to address the need for restorative repair for the Referenced AD, we intend to pursue validation testing, using this same philosophy, targeting repairs for primary structures of the fuselage.**

- **The author believes, from experience, that a pre-kitted, pre-consolidated (high pressure de-bulk), designed repair kit is the very best method for establishing reliable, restorative composite repair. Each of the historical examples shown in this pitch have performed their mission flawlessly, for a long period of time, after large areas of their structure were repaired using this philosophy. Method, Technique, and Process Documentation, along with a capable NDI plan are also required. And….PRACTICE.**

- **Spirit Global Customer Supply & Support currently has the ability to supply the industry with both repair kit types on an as-needed basis to more capably, and quickly, fulfill the need to comply to AD2012-05-02. (July 2015)**

- **Although it remains to be seen, the knowledge and repeated application of a standardized kit, supported by validation testing and documentation, has the opportunity to result in faster approvals.**

Author's Biography

John M. Welch

- Boeing Associate Tech Fellow, Spirit Technical Fellow, Composite Structures, Chief Scientist-GCS&S
- Affiliations, SAMPE, CACRC, MIL-HDBK-17, FAA symposiums, AW&ST, UBM, NIAR, NCAT
- Product owner for nacelle designs on 737NG, 747,757, 767,777, and A320NEO proposal
- Extensive background of experience with large database of composite coupon and full scale testing
- Performed several significant forensic investigations for FAA, AAIB, NTSB involving composite materials
- 29 years composite design/analysis/test/fleet/repair experience
- Stress, Design, MRB Background
- 300+ Composites Field Repairs performed to date

Publications, Presentations, and Articles – Repair Related

"Nacelle Configurations, Repair, and Test Results," Author, Commercial Airframe Composites Repair Committee/MIL-HDBK-17 symposium, Miami, FL, May 20, 2002

"Composite Repairs – Nacelle Applications, Author, Cytec Engineered Materials Technical Service quarterly meeting, Phoenix, AZ, November 2003

"Composite Nacelles: Flying toward new horizons", High Performance Composites, May 2004

"Bonded Repair of Aircraft Composite Sandwich Structures" Author, February 2004, Department of Transportation, Federal Aviation Administration, Office of Aviation Research

"Wait 'Till it's Broken: Innovations in High Performance Composites Repair", Composites Fabrication magazine, Contributor, September 2004

"Safe Composite Repairs – Substantiation Linking Repair Test Data to Observed Fleet Performance" FAA Workshop-Composite Damage Tolerance and Maintenance, Chicago, IL July 19-22, 2006

"Repair Design, Test, and Process Considerations for Lightning Strikes", FAA/Commercial Airframe Composites Repair Committee/MIL-HDBK-17 symposium, Amsterdam, Netherlands, May 7-11, 2007

"Lightning Strike Testing Results on Honeycomb Panels Protected with a Series of Metal Mesh Products", Society for Advancement of Materials and Process Engineering, June 5, 2007, Baltimore, MD

"Lightning Strike Protection and Damage Prevention Kit", Author, for the Society for Advancement of Materials and Process Engineering, June 5, 2007, Baltimore, MD

"Large Area Repair for Compliance on a Commercial Nacelle Inner Wall of the Thrust Reverser", Society for Advancement of Materials and Process Engineering, June 6, 2007, Baltimore, MD

"Fleet Repairs of Nacelle Composites" International Forum on Composite Applications for Large Commercial Aircraft, Shanghai, China, February 25, 2008

"A Large Area Acoustic Repair on the Inner Wall of the Thrust Reverser", Society for the Advancement of Materials and Process Engineering, Long Beach, CA, May 22, 2008

"Experience with Large Bonded Repairs: Observations on Classifications, Substantiations, Approvals and Fleet Performance," FAA Workshop on Damage Tolerance, Maintenance, & Crashworthiness, Atlanta, GA , May 18, 2011

""Spirit Experience with Large Bonded Repairs: Observations on Substantiation, Approvals, and Fleet Performance", Aviation Week and Space Technology America's MRO Conference, Dallas, TX April 4, 2012

"Best Practices in Advanced Material Repair", Aviation Week and Space Technology MRO Americas Convention, Georgia World Conference Center Atlanta, GA, USA, April 17, 2013

"A Perspective on MRO Trends in Advanced Material Repair", Aviation Week & Space Technology MRO Europe, Excel Convention Center, London, UK, September 24, 2013.