"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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September 15, 2015

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Spirit Worldwide Operations

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

Spirit AeroSystems is the World’s Largest Independent Supplier of Commercial Airplane Assemblies and Components.

Spirit’s Global Footprint Continues to Expand
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.

Mission:
To be the preferred Propulsion Hardware and Services provider in the world.

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

[Images of composite structures and repair stations]
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

Consolidated Repair Patch being placed

Cured Repair Patch

Restored Perforations

Final Painted Repair

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.
Examples of Practiced Repair Kits – Past Experience

Large Area Trans-Sleeve Repair

- 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

- Core Replaced
- Perforate Restored
- Solid Side Replaced

Circa 2002

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

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
## Example Test Matrix: Tension, Static, RT

<table>
<thead>
<tr>
<th>Loading Modes</th>
<th>Specimen Configuration</th>
<th>Repair Type</th>
<th>Repair Material</th>
<th>BVID</th>
<th>Total Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (5.5 x 11.5)</td>
<td>Repair Baseline 0.50 inch/ply overlap using 3/8 inch cell core</td>
<td>1 D W/D = 1</td>
<td>Gr/Ep 3K-70-PW, with Adhesive Gr5, over Core C1, TIII, Gr 4.5 core</td>
<td>No Impact</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 D W/D = 3.7</td>
<td></td>
<td>Impact</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Repair Baseline 0.50 inch/ply overlap using 1/8 inch cell core</td>
<td>1 D W/D = 1</td>
<td>Gr/Ep 3K-70-PW, with Adhesive Gr5, over Core C6, TV, Gr 3 core</td>
<td>No Impact</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 D W/D = 3.7</td>
<td></td>
<td>Impact</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0.25 inch/ply overlap using 3/8 inch cell core</td>
<td>1 D W/D = 1</td>
<td>Gr/Ep, 3K-70-PW, with Adhesive Gr5, over Core C1, TIII, Gr 4.5 core</td>
<td>No Impact</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 D W/D = 3.7</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>0.15 inch/ply overlap using 3/8 inch cell core</td>
<td>1 D W/D = 1</td>
<td>Gr/Ep, 3K-70-PW, with Adhesive Gr5, over Core C1, TII, Gr 4.5 core</td>
<td>No Impact</td>
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<td></td>
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<td>5</td>
</tr>
<tr>
<td></td>
<td>Impact Calibration Specimens</td>
<td>2D .25” ply 3/8” cell core</td>
<td>Gr/Ep, 3K-70-PW, with Adhesive Gr5, core as noted above</td>
<td>Impact</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2D .25” ply 1/8” cell core</td>
<td></td>
<td>Impact</td>
<td>4</td>
</tr>
</tbody>
</table>

**TOTAL TENSION SPECIMENS:** 128

*Note: Current Validation Matrix coupon count is 278 coupons*
• 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
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

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

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

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

Total elapsed time to place the repair kit: 7.12 minutes
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, HD
- 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

Increasing Strain

BL-1  Repair A  Repair C  Repair E

Design Value

Increasing Strain

BL-2  Repair B

Increasing Strain

BL-3  Repair D  Repair F

Strain u-in/in  CV, %

Strain u-in/in  CV, %
Test Results – Compression, for a SB/AD Repair Kit

Flex Beam Compression

Edgewise Compression

Flex Beam Compression – Open Hole
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

![Bar chart showing test results for Pin Bearing with increasing bearing stress for BL-1 and Repair E. The design value is indicated for each sample.]
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Non

Technical Data ECCN: EAR99

Repair Road Map—Pyramid to Successful Repairs

Reliable Fleet Performance

Successful Repair Performance

Accepted Repair Documentation Approvals Readily Supplied

Well Executed NDI Plan/Part Standard

Practiced and well Documented Repair Method detailing materials, processes, technique, thermocouple placement, heat blanket locale, bagging, vacuum, etc.

Technician Training on specific repair methods, specific repair configuration, specific repair environment, tools and methods to comply – Practice, Practice, Practice

Preparation of tooling, tool assist method, mylars, templates, environment requirements such as tents, De-humidifiers, etc. Certification of applicable repair machines, heating blankets, T/Cs etc as applicable.

Structural Test Plan preparation, test matrix definition, coupon preparations, small scale to full scale if required, Environmental conditioning, contaminant characterization, effects on bond line integrity, NDI focused plan, all to be included in the basic “Repair Strategy”

Basic Define of repair configuration, substrate and repair materials, processes, geometry, orientations, necessary components of the design such as dis-assembly and assembly if required, components needing to be procured for the repair, logistics of the location of repair, focus on technician readiness, time line established to target of repair event, mobility of repair equipment and tooling if required, focused criteria to point toward successful repair performance and readily accepted substantiation.

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

May 29, 2014

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Well Executed NDI Plan/Part Standard

Opened Repair Documentation Approvals Readily Supplied

Successful Repair Performance

Reliable Fleet Performance

July 11 2014

June 26, 2014

June 7, 2014

July 11, 2014

August 2014

April 2015

July 2014 thru Mar 2015

Inception

May 29, 2014

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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.
John M. Welch

Author’s Biography

- 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 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 ’Til 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


"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


"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