CMH-17 Substantiation of Bonded Repair (SoBR)
Supportability WG – Chap. 14 (Rev H)

• Overview of SoBR
  ➢ Background
  ➢ FAA Bonded Repair Initiatives
  ➢ SoBR Task Group
  ➢ CACRC/SoBR Work Split
  ➢ CMH-17 CACRC Document

References

Presented at:
CACRC Meetings at NCAT in Wichita, KS

By:
Larry Ilcewicz, Mike Borgman, Allen Rauschendorfer, Larry Gintert

Date:
June 24-27, 2019

SoBR-TG:
▪ AIRBUS ▪ BOEING ▪ BOMBARDIER
▪ DELTA ▪ EMBRAER ▪ EASA ▪ FAA
▪ FOKKER ▪ LMC ▪ LUFTHANSA
▪ LUXAIR ▪ RAYTHEON ▪ SPIRIT
▪ TCCA ▪ USAF ▪ USN ▪ UTAS
Michael Borgman: Background

Performance Architecture
SPIRIT AeroSystems, Inc.

- 2019 Spirit Distinctive Capability Leader
- 2018 Chief Engineer – Airbus Fuselage
- 2009 A350 Fuselage (Technical leadership)
- 2007 Business jet (TR Validation FEM/test)
- 2001 787 Fuselage (Effects of Defects, Repair)
- 1996 777/737 TR, Fan Cowl, Inlet (EoD, Repair)
- 1995 Premier 1 Wing (Thin Wing Architecture)
- 1989 F-16, A-12, X30, F-22 (Research, Methods, Analysis)
- 1988 Tomahawk & Advanced Cruise Missiles
- 1982 Composites Research (U of WY. D F Adams)
- 1979 Composites Production Manager
- 1978 Composites shop Foreman
- 1977 Composites shop mechanic

External Leadership Activities - Guidance and Policy Development for Composite Aircraft Structure

- 2001-Present: Speaker FAA Composites Maintenance and Damage Tolerance Workshop Series (Chicago/Tokyo/Amsterdam)
- 2006-2011: Chairman SAE/International CACRC (Commercial Aircraft Composite Repair Committee)
- 2007-Present: Member FAA/EASA/TCCA Industry/Regulatory Steering Committee (Airbus, Boeing, Bombardier, Spirit)
- 2012-Present: Chairman FAA Aviation Safety Initiative – Bonded Structures - Substantiation of Bonded Repair
CMH-17 Efforts with Composite Repairs

- **CMH-17 Substantiation of Bonded Repair (SoBR) TG** was started by a FAA/industry working group in 2014
  - New content for PMC V3 Ch14 Supportability, Maintenance & Repair
  - Driven by Safety Management concerns with field engineering practices and approvals
    - FAA input at 2010 JAMS Seattle
      - CACRC numerous case-studies on bonded repairs with indication of problem
      - Attribute to technical challenges, insufficient training and economic pressure
    - Initiated development of best-practice substantiation standards
    - Falls under the CMH-17 Chapter 14 Supportability WG
  - Overall Goal: *Update CMH-17 with best industry practices for substantiation of bonded and bolted composite repair, while updating other sections as needed*
  - SAE CACRC Collaboration
    - To include “critical structures” *(defined in FAA AC 20-107B)* plus less-critical
CMH-17 Efforts with Composite Repairs

- Emphasis on knowledge transfer for what is needed
  - Not turn-key handbook methods that includes the substantiating data
  - Identifies technical hurdles faced by all, including OEM
  - Substantiation of a given repair starts with prerequisite information on materials and processes used for repair and base structure design
  - In essence, a given repair substantiation has two parts
    - Substantiate M&P alignment
      - M&P specifications = M&P Substantiation Building-block = M&P Finished repair
    - Substantiate structural assertions
      - Most often thru Building-block mechanical and physiochemical tests
  - The scope of coverage presented for each part is function of criticality
  - Building-block structural test irrelevant in absence of M&P alignment
SoBR Plans/Intent on CMH-17 Content

• Be consistent with OEM best practices
  – OEM’s attend and their involvement is sought

• Address specific repair details
  – Substantiation typically requires data with correlated analyses
    • Often semi-empirical or to avoid failure not predict strength
  – Prerequisites needed in proposing a repair design
    • Includes sufficient proof of base structure process equivalency

• Largest inputs to V3, Ch14 §14.6, 14.7 and 14.12
SLC Supportability WG Meetings

- **Work completed through Wichita, 2017 Yellow Pages**
  - St. Paul (2016) complete chapter reorganization and outdated chapter updates
  - SLC (2017) Initial work on Sec 14.6 (Composite & Metalbond Structure Repair)
  - Wichita (2017) Most remaining parts of 14.6.2 Prerequisites for Repair

- **Work planned through 2019**
  - Charleston (2018) Final subsection of 14.6.2 Prerequisites for Repair, example bolted repair and new outline for Section 14.6.4 (Repair Substantiation)
  - SLC (2019) Initial work on Sec 14.6.4 (Repair Substantiation)
  - Wichita (2019) Remaining Sec 14.6.4 (Repair Substantiation) & case studies

- **Rev. H goals: Done with YP updates by SLC (2021)**
  - “Joint repair substantiation” to minimize cost
    - analysis/tests/design criteria/constraints
  - Increased coordination with V3/Ch10 (Bonded) and V3/Ch11 (Bolted) Analyses
    - SoBR(Analysis)-TG

- **Challenges (where help is welcomed)**
  - *OEM best practices* include proprietary prerequisite data and design procedures that are not readily available to airlines or repair orgs. (making substantiation difficult)
  - *Experienced resources* have provided the necessary steady, yet slow support.
### Active Bonded Repair Initiatives

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<tr>
<td><strong>Bonded Repair Size Limits Policy</strong></td>
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**CACRC Metal Bond and Composite Bonded Best Practices (AIRs):** Document best practices in metal bonding and composite sandwich bonded repair for previously substantiated repairs.

**CMH-17 Composite Repair Structural Substantiation (Vol. 3 Ch. 14):** Document guidelines, recommended prerequisites, qualification data, M&P specifications, design criteria, design details, criteria, analysis and test protocol for bonded repair structural substantiation.

**AC 65-33 (Composite Maintenance Training Guidance)**

**Updates:** Work with industry to update AC 65-33

**Best Practices in Bonded Repair:** Note to summarize and reference new international standards (SAE) and guidelines (CMH-17).

**Short Course for Repair Substantiation, and Approval:** Develop short course for regulatory and industry engineering designee on bonded & bolted repair design, structural substantiation, and approval.

**June/2019 Updates:** Continuous schedule adjustments related to available resources to support the efforts from industry and regulatory bodies.

**Research Support to Bonded Structure Initiatives, Including Bonded Repair:** Benchmark industry practices and identify potential safety problems to support the development of regulatory policy, guidance and training that mitigate risks. This research will also include inspection method and other maintenance technology evaluations.

**2019 FAA/Industry Workshop to review Advances at Wichita CACRC Meetings**

**2020 FAA/Industry Workshop for Beta Course Review**
### CACRC Main Meetings (Monday, June 24)

<table>
<thead>
<tr>
<th>Time</th>
<th>Subject</th>
<th>Presenter</th>
<th>Organization</th>
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<tr>
<td>8:30 am</td>
<td>Overview of SoBR Working Group</td>
<td>Mike Borgman</td>
<td>Spirit</td>
<td>Mike- Intro to SoBR (see LI, 6/26 1 PM, FAA SoBR Initiatives/background/links) Allen – General CMH-17/CACRC split (+ charts linking SoBR to CACRCRefs.)</td>
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<td>Allen Rauschendorfer</td>
<td>FAA</td>
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<tr>
<td>1.00 pm</td>
<td>Substantiation of Bonded Repairs</td>
<td>Larry Ilcewicz</td>
<td>FAA</td>
<td>Larry – More complete Intro to SoBR Initiatives (incl. COS ties, All Goals, other related FAA Initiatives – courses, TSO, progress to date, final deliverables, what it is and what it is not). Show the full chapter outline, including progress in updates by the SoBR TG (outside 14.6.4)</td>
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<td></td>
<td></td>
<td>Mike Borgman</td>
<td>Spirit</td>
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<tr>
<td>1.30 pm</td>
<td>CACRC Documents and SOBR</td>
<td>Ray Kaiser</td>
<td>CACRC</td>
<td>Charts from Allen’s part of the first day pitch + Ray’s own charts describing related CACRC goals/as well as anything he has learned from being part of SoBR TG</td>
</tr>
<tr>
<td>2.00 pm</td>
<td>Case Studies</td>
<td>Mike Borgman</td>
<td>Spirit</td>
<td>Overview of Case Studies, why (to demo an engineering approach), what kinds (real vs. hypothetical), some with no given solution, &amp; some lucky ones (close to no solution)</td>
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### CACRC Main Meetings (Wednesday, June 26)

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<td>10.30 am</td>
<td>CMH-17 Workshop: FAA Advances, <strong>Industry Standards &amp; Integrated Product Development</strong></td>
<td>Larry Ilcewicz FAA</td>
<td>IPT and product value ▪ industry standards that will work vs. turn-key approaches not available ▪ why analyses don’t work without data ▪ engineering solutions and things the FAA is proposing for the current SOA.</td>
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<td>11.00 am</td>
<td>CMH-17, Vol. 3/Chapter 14 Content <strong>Prerequisites for Bonded Repair</strong></td>
<td>Mike Borgman Spirit</td>
<td>§ 14.6.2 ▪ prerequisites likely most difficult part of structural substantiation ▪ including relationships with CACRC.</td>
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<tr>
<td>11.30 am</td>
<td>CMH-17, Vol. 3/Chapter 14 Content <strong>Substantiation of Bonded Repair</strong></td>
<td>Larry Ilcewicz FAA</td>
<td>§ 14.6.4 (except 14.6.4.5) ▪ subsection goals ▪ repair substantiation impossible without meeting material and process prerequisites (as well as mechanical proof of structure)</td>
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<td>1.00 pm</td>
<td>CMH-17, Vol. 3/Chapter 14 Content <strong>Substantiation of Bonded Repair, cont.</strong></td>
<td>Larry Gintert CMH-17</td>
<td>§ 14.6.4.5 certification by-analysis-supported-by-tests and certification <strong>primarily-by-tests</strong> as related to efforts needs and related costs, incl. common tests for both).</td>
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## CACRC Main Meetings Thursday, June 27 (part 2)

<table>
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<tr>
<th>Time</th>
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<th>Content Description</th>
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| 1.30 pm| CMH-17, Vol. 3/Chapter 14  
Content Other sections in work (e.g., analysis). | Mike Borgman  | Details:  
- Outlines for § 14.7: Analysis for Composite and Metalbond Repairs (bolted & bonded repairs)  
- Note relationship with V3 Ch10 & 11  
- Unique analysis challenges for real repairs. |
| 2.00 pm| FAA/Boeing R&D: Bonded Repair Size Limits Analyses and Tests            | John Lin      | Invited speaker  
- Emphasis on tests/analyses that cover BRSL expectations  
- How to eliminate conservative assumptions on actual BRSL constraints. |
| 3.00 pm| CMH-17, Vol. 3/Chapter 14  
Case Study #2 Repair                                                   | Mike Borgman  | Details:  
- Table of all case-studies  
- Completed case Study #1 (Metalbond flap wedge)  
- SoBR-TG Case-Study #2 (fuselage damage outside SRM) |
| 3.30 pm| CMH-17, Vol. 3/Chapter 14  
Case Study #2/#9 Split                                                   | Mike Borgman  | CMH-17  
Split as required between SoBR-TG CS #2 & #9 |
| 4.00 pm| CMH-17, Vol. 3/Chapter 14  
Case Study #9 Repair                                                     | Larry Gintert | CMH-17  
SoBR-TG Case-Study #9 (GA Wing Spar/Skin) |
WORK SPLIT: CACRC/CMH-17

Allen Rauschendorfer (FAA)
Damage Assessment & Repair

Substantiation Data:
- Aircraft loads development
- Proven analysis methods
- Base material allowables data
- Repair materials allowables data
- Base/repair material bond qualification
- Fastener/bolted joint data
- Environmental data
- Proof of structure testing (incl. BRSL check)
- Design values: data compatible with analysis (e.g., effects of defects, repair structural details, damage tolerance, etc.)
- Instructions for continued airworthiness
- Etc

Substantiation of Bonded Repair (SOBR)
(including thoughts for bolted repairs)

Repair procedures/standards:
- Technician Training
- Standard repair procedures
- Best practices
- Inspection methods/equipment
- Repair materials
- Approved facilities
- Process controls
- Etc
FAA Recommended Work Split and Interface

**SAE CACRC**
- Repair lessons learned
- Best practices/standards for repair processes, procedures, training & design for maintenance guidelines
- Best practices/standards for practical maintenance inspection methods
- SAE AMS specifications and data for repair materials
- New initiatives?

**CMH-17**
- Standards/guidelines for statistics, test methods and data reporting
- Published shared databases for base material properties and other non-product specific design data
  - Linked with SAE P-17 AMS
- Guidelines for M&P QC, structural analysis, certification, design, and many facets of structural substantiation

**Areas of coordination between CACRC and CMH-17:**
- Best practices for repair processes, procedures, training and inspection
- Protocol for material qualification equivalency, M&P specs
- Design for supportability (inspectability, repairability and maintainability)
- Protocol for repair design, structural substantiation (M&P prerequisites, analyses & tests) and other interfaces (e.g., defect/damage inspection protocol)
- CMH-17 publishes repair material databases
CMH-17 and CACRC Support to Industry

- CMH-17 and CACRC provide technical guidance on material & process control, design, test methods, data needs/test matrices, analyses, structural substantiation, maintenance (inspection & repair), including:
  - Statistics and data treatment/review
  - Test methods/matrices and databases
  - Manufacturing quality control
  - Certification considerations
  - Design and analysis
  - Bonded and bolted joints
  - Damage tolerance and durability
  - Repair processes and procedures
  - Inspection methods and guidance
  - Other special considerations (e.g., crashworthiness)
  - Knowledge transfer, guidelines and training protocol

- CMH-17 and CACRC are linked with FAA Aviation Safety (AVS) Composite Initiatives, which focus on current industry needs
  - Also linked with the other international standards org. (SAE, ASTM)

- CMH-17 Conducts Joint meetings with
  - National Center for Advanced Materials Performance (NCAMP)
  - SAE AMS P-17 Composite Materials Committee
  - ASTM Committee D30 on Composite Materials
Other Thoughts on CACRC and CMH-17

• Both are driven by industries’ need for composite standardization and practical guidelines and have learned to be resilient if not patient
  – Deliverables generated by volunteers take a long time to develop
  – Can’t afford to have duplication of efforts by different organizations
  – Travel costs and time away from primary work duties reduces meeting attendance/contribution, leading to a need for virtual meetings

• Both have limited work force directly involved in developing deliverables (particularly those in leadership roles)

• Both have members that join for educational purposes (and efforts to both gain knowledge, while supporting initiatives)

• Work should be split to best utilize the talents coming to meetings and contributing to deliverables
  – Potential training opportunities during meetings should be pursued to offset meeting costs and allow more efficient working meetings
  – Put the students to work in review and letting us know whether they understand our draft content
3.7.3 Technical reports “Teaching Points for an Awareness Class on “Critical Issues in Composite Maintenance and Repair” [SAE Airspace Information Report (AIR) 5719, XXX 2008] [Note: This document is accepted by FAA/EASA/TCCA.]

• REFERENCES:

  14.7.2(a) SAE Aerospace Recommended Practice (ARP) 4916, “Masking and Cleaning of Epoxy and Polyester Matrix Thermo-setting Composite Materials,”
  14.7.2(b) SAE Aerospace Recommended Practice (ARP) 4977, “Drying of Thermo-setting Composite Materials,”
  14.7.4.4(a) SAE Aerospace Recommended Practice (ARP) 5256, “Mixing Resins, Adhesives, and Potting Compounds,”
  14.7.4.4(b) SAE Aerospace Recommended Practice (ARP) 5319, “Impregnation of Dry Fabric and Ply Lay-up,”
  14.7.4.4(d) SAE Aerospace Recommended Practice (ARP) 5143, “Vacuum Bagging of Thermo-setting Composite Repairs,”
  14.7.4.4(e) SAE Aerospace Recommended Practice (ARP) 5144, “Heat Application for Thermo-setting Resin Curing,”
  14.7.5.2 SAE Aerospace Recommended Practice (ARP) 4991, “Core Restoration of Thermo-setting Composites,”
  14.11.1(b) SAE Training Document AIR 4938, “Composite and Bonded Structure Technician/Specialist: Training Document,”
  14.11.1(c) SAE Training Document AIR 4938, “Composite and Bonded Structure Technician/Specialist: Training Document,”
• **14.7.1 Damage removal and site preparation**

  – Paragraph 2: It has also been shown that patches bonded to parent composite material containing more than a nominal (0.3% moisture content by weight) experience lower adhesive bond strengths. For honeycomb parts cured at room temperature, presence of moisture is undesirable, particularly if the core material is aluminum. SAE ARP 4916 (Reference 14.7.2(a)) and ARP 4977 (Reference 14.7.2(b)) give guidelines how the composite part should be cleaned and dried before proceeding with the repair.

• **14.7.4.4 Procedures**

  – Paragraph 2: How to properly mix the resin is described in SAE document ARP 5256 - Resin Mixing (Reference 14.7.4.4(a)) and NAVAIR 01-1A-21 (Reference 14.7.3.4(a)). The impregnation of the dry fabric with the mixed resin is described in SAE document ARP 5319 - Impregnation of Dry Fabric Application of Repair Plies (Reference 14.7.4.4(b)).

  – Paragraph 5: Care must than be taken not to puncture the bag. NAVAIR 01-1A-21 (Reference 14.7.3.4(a)) has a good description where the thermocouples should be placed. SAE ARP 5143 - Bagging (Reference 14.7.4.4(d)) gives guidance as to proper bagging techniques.

  – Paragraph 6: The maximum thermocouple reading is usually used as a control on the maximum allowed temperature. Cure time is adjusted by monitoring the minimum thermocouple reading. After the cure is completed the repair assembly is cooled before relieving vacuum pressure. More details on this subject are contained in SAE ARP 5144 – Heat Application for Thermosetting Resin Cure (Reference 14.7.4.4(e)).
CACRC References in CMH-17 Rev. G

• 14.7.5.2 Core Restoration

  – Paragraph 2: For partial-depth damage, different methods can be used to attach the replacement honeycomb to the parent honeycomb as shown in Figure 14.7.5.2(b). The two methods describe the prepreg/film adhesive bonding and the wet lay-up bonding. Both of these bonding methods were discussed in Section 14.7.4.3. A general description of how to perform core restorations for simple configuration is contained in SAE ARP 4991 - Core Restoration (Reference 14.7.5.2).

• 14.11.1 Training

  – Paragraph 2: Inspectors need specialized training in the use of the range of inspection techniques utilized for composite materials. Good eyesight and hearing are also valuable attributes. The NDI requirements for composite repair are quite heavy and necessitate specialized techniques. The specialized training is covered in the SAE document AIR 5279, Composite and Bonded Structure Inspector: Training Document (Reference 14.11.1(a)).

  – Paragraph 4: This training should include a classroom lecture to provide in-depth information into the specifics of working with composite materials, in addition to hands-on instruction so that proficiency can be demonstrated in practice. SAE document AIR 4938 (Reference 14.11.1(b)) provides a curriculum for such training. This should be a prerequisite to on-the-job training (OJT) with actual components prior to achieving certification as a composite technician.

  – Paragraph 6: A materials and process engineer to support materials testing and composite processing will be needed. These engineers must have a firm understanding of thermosetting material chemistry and rheology. SAE document AIR 5278 (Reference 14.11.1(c)) provides guidance for a curriculum for a training program.
14.1 Introduction

Paragraph 7: Since 1991, the Society of Automotive Engineers (SAE) Commercial Aircraft Composite Repair Committee (CACRC) has been working, along with the Composite Materials Handbook (CMH-17), to develop and improve maintenance, inspection, repair materials and repair practices for commercial aircraft composite structures and components, and to reduce maintenance costs. The Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) rely on CACRC and CMH-17 to benchmark and document industry best practices.

14.6.3.2.4.3 Repair Process


Paragraph 4: There may be multiple drying cycles depending on part condition or the heat application system used for cure. Refer to SAE ARP4977 – Drying of Thermosetting Composite Materials for guidance on this topic.

Paragraph 14: Additional processes are required for wet layup, such as weighing out the ingredients and mixing the neat resin with catalyst (per SAE ARP5256 – Mixing Resins, Adhesives and Potting Compounds (Reference 14.7.4.4(a)) or NAVAIR 01-1A-21 (Reference 14.7.3.4(a)) and wetting the dry cloth plies with mixed resin (per SAE ARP 5319 – Impregnation of Dry Fabric and Ply Lay-up (Reference 14.7.4.4(b)).

Paragraph 25: Additional resources for bagging and heat application are SAE ARP 5143 - Bagging (Reference 14.7.4.4(d)) gives guidance as to proper bagging techniques.

Paragraph 26: More details on this subject are contained in SAE ARP 5144 – Heat Application for Thermosetting Resin Cure (Reference 14.7.4.4(e)). The use of alternative heat sources such as heat lamps, ovens or autoclaves are also covered in SAE ARP5144.

14.6.3.2.5.3 Core Restoration

Paragraph 2: A general description of how to perform core restorations for simple configurations is contained in SAE ARP 4991 - Core Restoration (Reference 14.7.5.2).
Questions/Comments?
Backup Slides
Sections of Chapter 14 sent to Yellow Pages for Rev H after St. Paul, 2016

14.1 Introduction
14.2 Important Considerations
14.4 Inspection
14.5 Damage Assessment
14.8 Composite Repair of Metallic Structure
14.9 Maintenance Documentation
14.12 Repair case studies
  14.12.1 Introduction
  14.12.2 Case study #1 – Substantiation of bond process changes

Sections of Chapter 14 sent to Yellow Pages for Rev H after SLC, 2017

14.6 Repair of Composite and Metalbond Structure
  14.6.1 Introduction
  14.6.2 Prerequisites for the repair of composite and metalbond structure
    14.6.2.8 Equipment calibrations
    14.6.2.9 Technician/inspector/engineer qualifications and training
    14.6.2.10 Tooling and repair work station challenges to ensure proper form and fit
    14.6.2.11 Quality Control
  14.6.3 Repair design and processing
    14.6.3.1 Design criteria
    14.6.3.2 Repair design and processing
      1. Introduction
      2. 14.6.3.2.2 Damage removal and site preparation
      3. Bolted repair
        1. Repair concepts
        2. Repair materials
        3. Repair processing
      14.6.3.2.4 Bonded repair
        1. 14.6.3.2.4.1 Repair concepts
        2. 14.6.3.2.4.2 Repair materials
    14.6.3.4 Repair quality assurance
Back-up (Details)

Sections of Chapter 14 sent to Yellow Pages for Rev H after Wichita, 2017

14.6.2 Prerequisites for the repair of composite and metalbond structure
  14.6.2.1 Approved data
  14.6.2.2 Material and process specifications
  14.6.2.3 Purchase control
  14.6.2.4 Raw material storage and handling
  14.6.2.5 Qualified materials
  14.6.2.6 Facilities and work space control

Sections of Chapter 14 sent to Yellow Pages for Rev H after Charleston, 2018

14.6.2.7 Contact and non-contact materials
14.6.3.2.3.4 Example of a bolted repair

New outline for Section 14.6.4 Repair substantiation

Plan for Yellow Page Submittal after SLC, 2019

Section 14.6.4 Composite and metalbond repair substantiation

14.6.4.1 Introduction
14.6.4.2 Aircraft regulations and requirements
14.6.4.3 Guidance and policy Statements
  14.6.4.3.1 Structural criticality and other considerations
14.6.4.4 Substantiation approaches for-structural repairs
  14.6.4.4.1 Prerequisites and design data needs
  14.6.4.4.2 Repair substantiation predominantly by test
  14.6.4.4.3 Repair substantiation by analysis supported by test
14.6.4.5 Building block analysis and test correlation
  14.6.4.5.1 Introduction to Building Block Methodology
14.6.4.6 Temporary or time-limited and interim repairs
14.6.4.7 Continued airworthiness