DOT/FAA/TC-14/20

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Nonconforming Composite Repairs: Case Study Analysis

November 2014

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-14/20		

4. Title and Subtitle	5. Report Date
NONCONFORMING COMPOSITE REPAIRS: CASE STUDY ANALYSIS	November 2014
	6. Performing Organization Code
7. Author(s) Charles Seaton and Sarah Richter	8. Performing Organization Report No.
9. Performing Organization Name and Address Heatcon Composite Training, Inc 600 Andover Park East Seattle, WA 98188	10. Work Unit No. (TRAIS) 11. Contract or Grant No. SUB315229-1 (grant# R49721)
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Northwest Mountain Regional Office—Aviation Safety Directorate 1601 Lind Ave., SW Renton, WA 98057	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code AIR-100

15. Supplementary Notes

The Federal Aviation Administration William J. Hughes Technical Center Aviation Research Division COR was Allan Abramowitz.

16. Abstract

The Federal Aviation Administration worked with a major airline to document case studies of faulty field repairs associated with composite components. Five instances of improper and faulty composite field repairs were selected, which had been previously analyzed by a major airline to capture common root causes as a guide to regulatory directions, communication, and training.

The documented scenarios identified root causes, which included inadequate technician training, incorrect composite repair techniques, and violation of proper procedures. Other related underlying contributing factors included the tendency of some practitioners to: equate the quality of surface aesthetics with structural integrity, provide quicker and more economic repair services by third parties through unapproved shortcuts and techniques, and apply approved repair processes outside the limitations that are specified by the Structural Repair Manual (SRM).

Common nonconformance issues among the case studies included: repairs approved for a specific application used on a different application, implementation of repairs that were outside limitations imposed by authorized documentation, such as the SRM, improper repair design analysis, improper repair techniques, and a lack of proper tools.

17. Key Words	18. Distribution Statement
Composite materials, Awareness, Safety, Critical, Maintenance, Repair, Training, Case study	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance and technical guidance provided by Dr. Larry Ilcewicz, the Federal Aviation Administration's Chief Technical Scientist for Composites.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ACRONYMS

CCC	Chromate conversion coating
DER	Designated engineering representative
FAA	Federal Aviation Administration
FEP	Fluorinated ethylene propylene
MRO	Maintenance, repair, and overhaul
OEM	Original equipment manufacturer
PAA	Phosphoric acid anodizing
RDL	Repair damage limits
SRM	Structural Repair Manual

EXECUTIVE SUMMARY

The Federal Aviation Administration worked with a major airline to document case studies of faulty field repairs associated with composite components. Five instances of improper and faulty composite field repairs were selected, which had been previously analyzed by the airline to capture common root causes as a guide to regulatory directions, communication, and training.

The documented scenarios identified root causes, which included inadequate technician training, incorrect composite repair techniques, and violation of proper procedures. Other related underlying contributing factors included the tendency of some practitioners to:

- Equate the quality of surface aesthetics with structural integrity.
- Provide quicker and more economic repair services by third parties through unapproved shortcuts and techniques.
- Apply approved repair processes outside the limitations that are specified by the Structural Repair Manual (SRM).

Common nonconformance issues among the case studies included:

- Repairs approved for a specific application that were used on a different application.
- Implementation of repairs that were outside limitations imposed by authorized documentation, such as the SRM.
- Improper repair design analysis.
- Improper repair techniques.
- Lack of proper tools.

In many cases, these issues could have been limited by increasing practitioner awareness through training; regarding the importance of proper techniques, procedures, and processes as a basis for assuring structural integrity; and conformance to aircraft type design by the repair design and its implementation. Specifically, proper training in the use, placement, and implementation of cure equipment (such as a hot bonder, heat and insulation blankets, and thermocouples) is an essential element to achieving a quality repair. Training should prepare repair technicians to recognize unapproved or unacceptable practices. Technicians should also be aware of what are accurate tooling practices that allow for duplication of the original part contour.

The case studies have been used to illustrate safety issues in a variety of forums:

- Presentations by regulatory agencies to public audiences to emphasize safety principles and need for guidance.

- Global composite repair working groups, such as the Commercial Aircraft Composite Repair Committee, with a particular emphasis on repairs implemented outside of SRM limitations.

- Incorporation of case studies in Revision G of the Composite Materials Handbook 17 chapter on safety management as actual illustrations.

- Use of case studies to enhance learning experiences.

Each of the case studies provides an excellent means of communicating root causes for inadequate safety management. One of the primary lessons is that safety management for repairs is a blend of disciplines, including team interactions, process conformance, and technical skills.

With regard to curriculum development initiatives, these case studies have been used to create discussion forums by which an instructor uses a questioning technique among students to allow discovery of specific teaching points. Use of actual scenarios provides further meaning and significance to the learning experience. The five case studies also illustrate common themes among nonconforming repairs.

1. INTRODUCTION

The use of fiber-reinforced composite materials has substantially increased in the commercial aircraft fleet. To ensure the continued airworthiness of the composite components in these aircraft, it is necessary to perform the required maintenance and repairs. However, the use of composite materials requires not only different design considerations than their metallic counterparts, but substantially different maintenance and repair considerations. Proprietary designs, limited information, and the lack of appropriate equipment and trained technicians have increased the difficulty for maintenance, repair, and overhaul (MRO) organizations to perform such repairs. The Aircraft Maintenance Manual and the Structural Repair Manual (SRM) supply information and guidelines concerning specified repairs. More extensive repairs can be performed under the direction of a designated engineering representative (DER) or by the original equipment manufacturer (OEM). The repairs must maintain the durability, ultimate strength, and residual strength of the original structure, and the repairs must be performed adequately to maintain continued operational safety [1]. Studies have been conducted to evaluate the repair quality performed by various organizations. To this end, the Federal Aviation Administration (FAA) has worked with a major airline to document case studies of faulty field repairs associated with composite components. Five instances of improper and faulty composite field repairs were selected that had been previously analyzed by the airline to capture the common root causes as a guide to regulatory directions, communication, and training.

The five case studies discussed in sections 2 through 6 identify root causes that include inadequate technician training, incorrect composite repair techniques, violation of proper procedures, and other related factors to nonconforming repairs.

2. CASE STUDY 1—OVERHAULED FLAP ASSEMBLY

2.1 KEY ISSUES

The key issues found in case study 1 were as follows:

- Not following guidance from authorized documentation, such as the SRM.
- Inadequate technician training in the use, placement, and implementation of cure equipment, such as a hot bonder, heat and insulation blankets, and thermocouples.
- Tooling practices that failed to duplicate the original part contour.
- Appropriate safety management procedures to ensure checks and balances in a team environment are needed.
- Incomplete documentation of prior repair disposition and incomplete documentation of the current repair.

2.2 SCENARIO

After receipt of an overhauled flap assembly, the airline observed that the assembly did not fit properly. Maintenance personnel indicated that the issue was due to the part's contour. A different contractor was selected to fabricate check inspection tooling to confirm the discrepant contour. The tooling was based on OEM data and was compared against a digital model of the OEM loft using a Coordinate Measuring Machine device, and also checked against a good part. When the overhauled flap assembly was placed on the tool, the trailing edge was out of contour at the outboard end by over 1.5 inches (figure 1).

Figure 1. Overhauled Flap Assembly Placed on Tooling That Served as a Check Fixture

The part was disassembled to determine whether the part could be restored to the required contours through repair. The lower skin and honeycomb core were removed, leaving only the spar and upper skin intact. During the disassembly, several observations were made:

- A prior MRO had removed and replaced large sections of honeycomb, including 20-inch segments that spanned the leading and trailing edges of the part, which were outside the SRM limitations.

- It was observed that the repairs used 250°F instead of 350°F prepreg repair materials and that the repaired areas exceeded the SRM limits on size (figure 2).

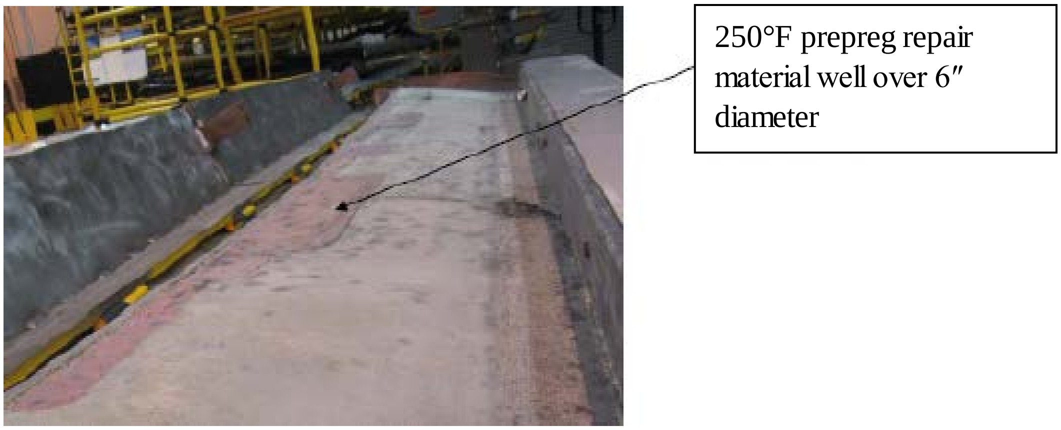

Figure 2. Repair That Incorrectly Used 250°F Prepreg Repair Material

- It was concluded that a previous repair had been performed by improperly using a hot bonder and heat blanket for part cure. This conclusion was reached by observing what appeared to be burn marks on the skin caused by heat blanket overheating (figure 3). This is frequently caused by the improper use of the hot bonder or placement of the thermocouples.

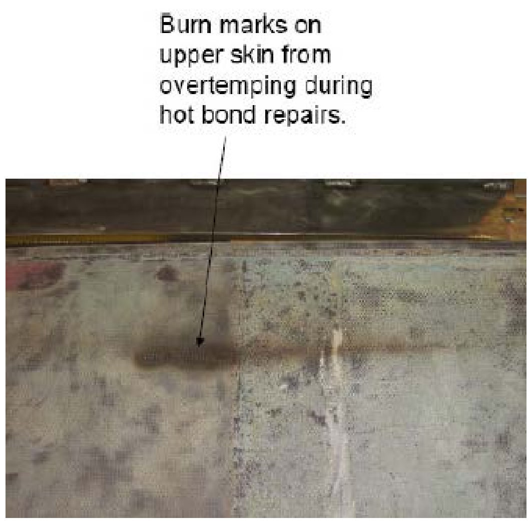

Figure 3. Skin Burn Marks Caused by Heat Blanket Overheating

- Not using tooling, or using tooling with incorrect contours during the repair, caused a warp condition on the spar. In figure 4, the lower skin and honeycomb had been removed and the spar would not conform to the tooling contour, even with substantial pressure on both ends of the part.

Figure 4. Out-of-Contour Condition of the Spar Resulting From the Use of Improper Tooling

In addition to the poor repair workmanship that was evident, there was no documentation substantiating the structural integrity of the repair design, materials, and processes applied to the flap. There was also no documentation on prior repairs, including the identification of the prior repair organization. The flap assembly was dispositioned as unusable and subsequently scrapped.

3. CASE STUDY 2—SLAT ASSEMBLY

3.1 KEY ISSUES

The key issues found in case study 2 were as follows:

- The design and repair did not use the latest configuration information for the part, including airworthiness directives and drawing updates.
- Not following authorized documentation, such as an SRM and recognizing procedures that are outside of the SRM limits.
- Tooling practices that failed to duplicate the original part contour.
- Safety management—checks and balances in a team environment.

3.2 SCENARIO

A leading edge (LE) slat (figures 5 and 6) was removed for inspection because of hail damage that extended the length of the slat. A tap test was performed, followed by ultrasonic inspection, which revealed core damage in addition to skin damage caused by hail.

The SRM cited repair damage limits (RDL) to the damaged assembly. Specifically, the SRM describes and authorizes a qualified repair only if the replacement of core and skin is less than 50% of the length of the part and the damage is to only one skin.
The repair was outside of the limitations imposed by SRM RDL requirements.

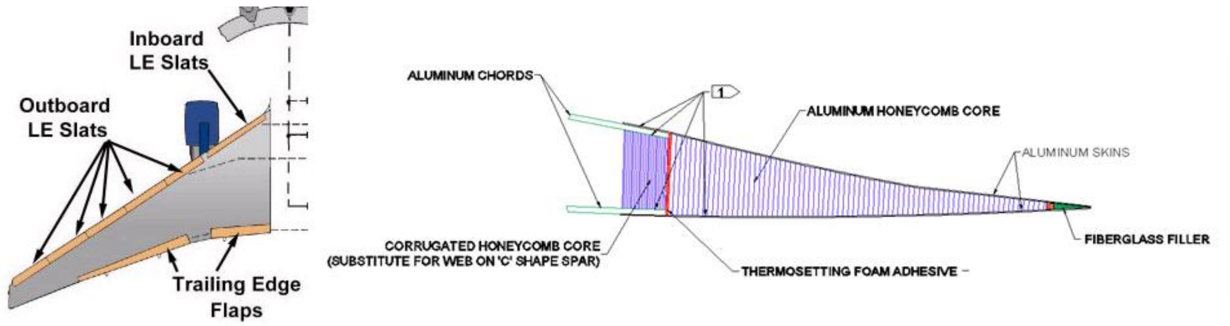

Figure 5. Schematics of Slat Locations and Cross-Section

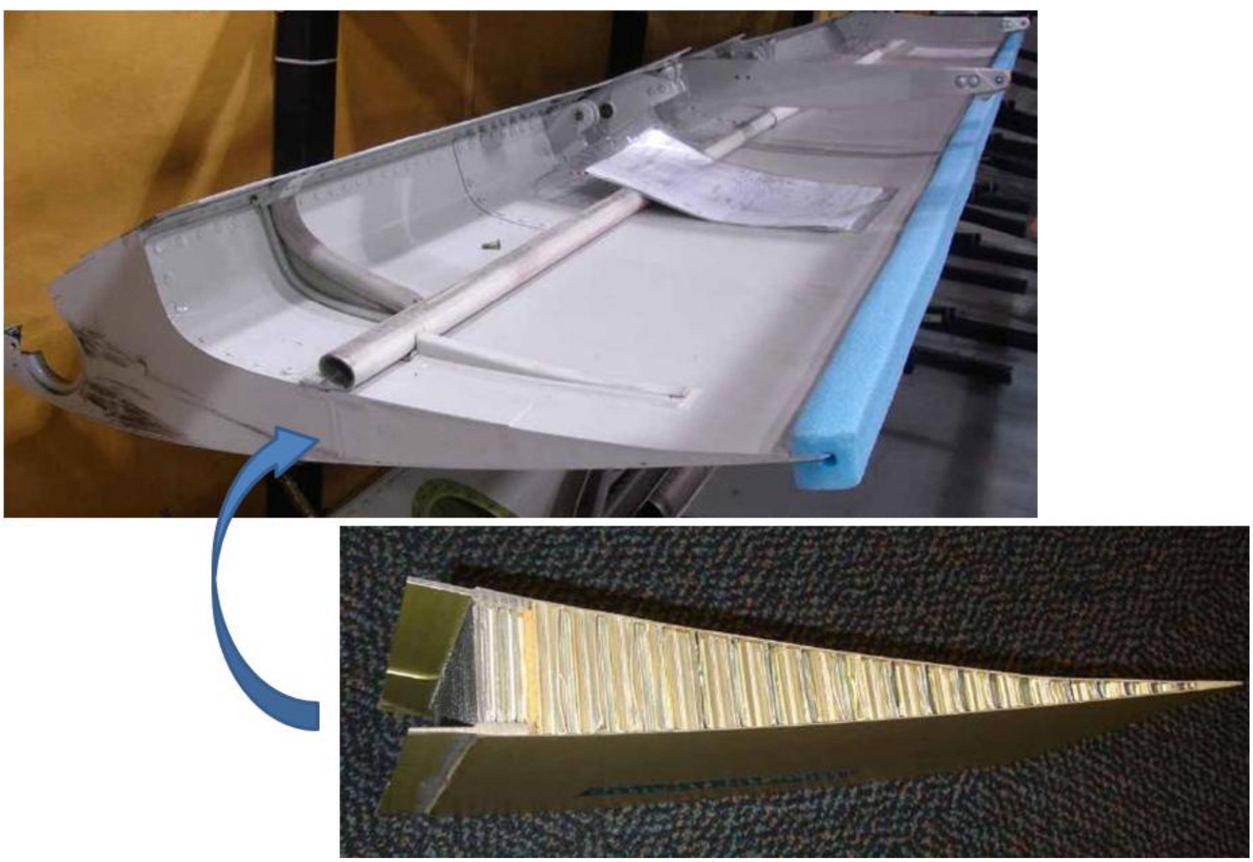

Figure 6. Slat Assembly and Wedge

An MRO was requested to rebuild the wedge to the latest approved configuration. The MRO had the wedge component listed on its capabilities list and was committed to having the latest configuration requirements, including service bulletins. The MRO had the required resources, such as DER support, to repair the part to compliance. The part was repaired and returned to the operator base. During an attempt to install the part by the airline operator, it was found that the configuration did not match the requirements. Further investigation revealed issues with drawing flagged note interpretation and configuration control (tooling contours and subassembly components) [2].

- The MRO engineering authorization paperwork referenced a flag note in the OEM engineering drawings that had subsequently been changed. The flag note (for curing the film adhesive at 250°F) in the OEM engineering drawing did not apply to the latest part configuration (for curing the film adhesive at 350°F), which was also referenced in the OEM's service bulletin.

  – The repair station submitted a Statement of Compliance With Airworthiness Standards – FAA form 8110-3 – regarding a repair procedure based on the incorrect flag note reference to the DER. The DER approved the part repair based on the unknowingly incorrect flag note reference.

  – Subsequently, quality assurance accepted the repair based on the data that conformed to the FAA 8110-3 requirements.

- The MRO used incorrect tooling, or no tooling, that resulted in warpage and prevented the wedge from fitting into the slat.

- The MRO used incorrect spar chords for replacement during the repair. This was clearly outside of the existing approved data and would require structural substantiation data, including material and process qualification, bond surface preparation compatibility assessments, and structural design data and analysis.

4. CASE STUDY 3—INBOARD FLAP HONEYCOMB REPAIR

4.1 KEY ISSUES

The key issues found in case study 3 were as follows:

- Not obtaining prior approval for a repair.

- Performing repairs that were not an approved repair design.

- Inadequate technician training to recognize unapproved or unacceptable practices.

- Not following the guidance from authorized documentation, such as the SRM.

- Tooling practices that failed to duplicate the original part contour.

4.2 SCENARIO

A commercial transport inboard flap was observed to have significant delamination between the metal skins and honeycomb core. The airline operator decided to send the part to a repair station for disposition and repair. Upon evaluation of the damage, the repair station proposed the replacement of the upper and lower skins and local honeycomb repairs, which had resulted from tearing of the original core during skin removal. The requested repair was subject to approval by the airline engineering department and its DERs prior to the work being initiated by the repair station. However, the repair station completed the repair without the required prior airline engineering repair approval and submitted the repair procedure to the airline after the repair was completed.

Upon reviewing the submitted repair procedure, the airline advised the repair station that a bond line test [3] would be required on a repair of this magnitude to show conformance to OEM tolerances on adhesive film thickness throughout the part.

Verification film testing is essentially part layup, part consolidation, and part cure, but without adhesive bonding. In other words, a test part is layed up with very thin (typically 0.001-inch-thick) fluorinated ethylene propylene (FEP) film placed above and below the adhesive film layers to prevent the adhesive from sticking to the prepared or faying metal/composite surfaces. The layup is processed normally, but is then disassembled after cure (because the film prevents adhesion) and is carefully examined for potential bond line defects. The indentations in the encapsulated adhesive layers verify correct detail fit and help determine if any bond lines are too thick or too thin. Although the very thin FEP film can be difficult to work with, especially on contoured parts, using verification film is the only way to determine bond line thickness in parts before actual bonding, whereas nondestructive inspection cannot do this[3].

The repair station did not perform a bond line test as requested by airline engineering. Instead, they chose to remove the skins a second time to show process conformance through destructive analysis of the bond line. In addition, instead of using dry ice methods to remove the skins, the repair station employed a heat-removal method.

After skin removal was completed, the repair station requested that the airline examine the flap assembly to gain approval of the repair procedure to reskin the flap and complete all repairs.

4.3 AIRLINE ASSESSMENT OF REPAIR PROCEDURE

The procedure for the airline assessment of repair is as follows:

1. Burn marks on the honeycomb core showed that the heat application during skin removal exposed the part to temperatures above acceptable limits (figure 7).

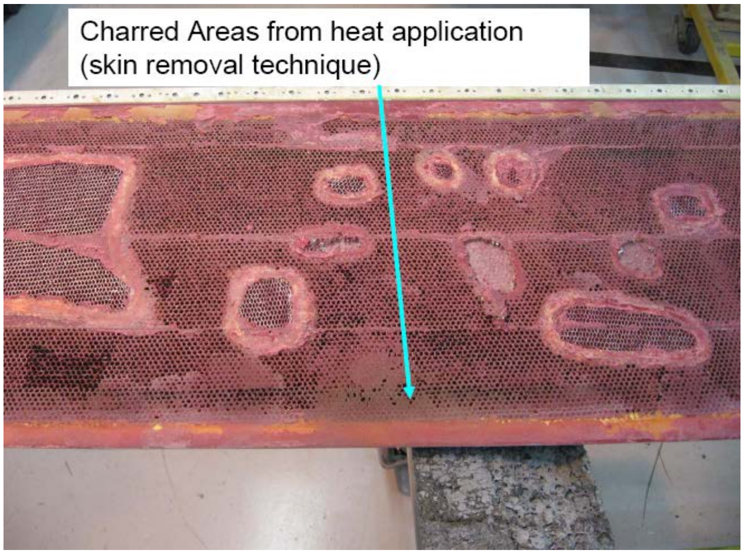

Figure 7. Damaged Honeycomb Core From Excessive Heating

2. There were areas at the inboard and outboard ends that had evidence of film adhesive porosity (small voids), which indicated that the BMS5-101 film adhesive had a thickness that exceeded OEM tolerances. This suggested that the tool used in the repair did not match the flap assembly correctly (figure 8).

Figure 8. Uneven Film Adhesive Thicknesses May Have Been Caused by Tooling Contour Inaccuracies

3. Several issues were discovered that related to improper ribbon direction of the replacement honeycomb core areas, SRM repair proximity limits, and honeycomb replacement core type (figure 9). The technician may have squeezed replacement core into the cut out area without regard to orientation, shape, and cell wall condition.

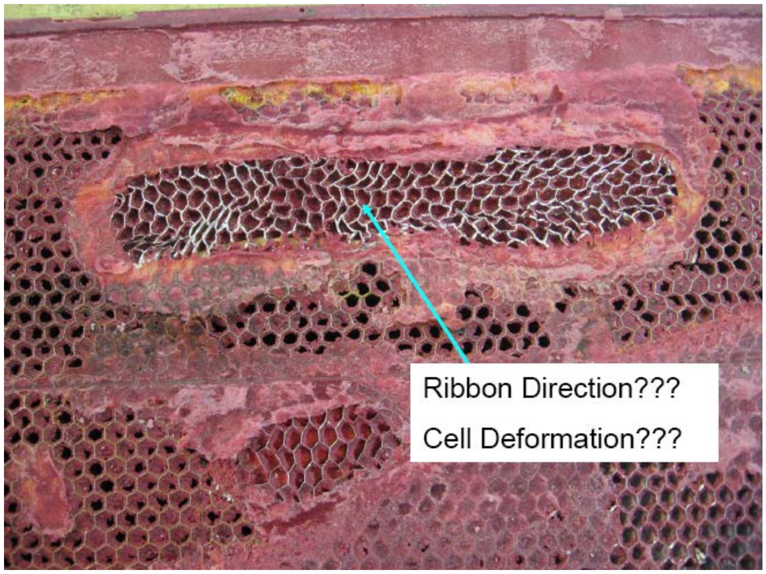

Figure 9. Poor Workmanship Resulted in Distorted Honeycomb Core

4. The core plug depth for all repair areas shown in figure 10 were 0.100-inch deep, which is far shallower than the SRM allows (The SRM requires that core plugs are greater than 1/3 of the full depth of the core, locally, to both skins). The repair station did not have access to full-depth shaped core replacement sections, and the technicians were forced to improvise.

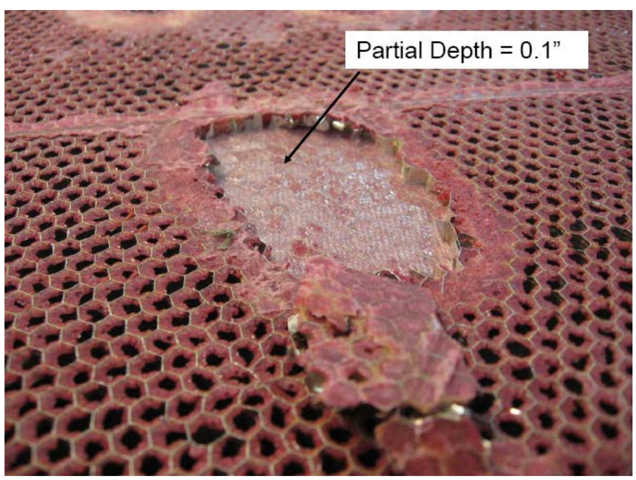

Figure 10. Incorrect Honeycomb Plug Dimensions Violated SRM Requirements

There were many unapproved processing procedures performed on the inboard flap panel assembly and the part did not meet structural requirements applied to a repair of this magnitude. There was no evidence of proper skin removal, core placement, and bonding tolerance assessments. In conclusion, the flap was reworked by the airline by replacing all honeycomb core and skins.

5. CASE STUDY 4—ADHESIVE BONDING AND SURFACE PREPARATION

5.1 KEY ISSUES

The key issues found in case study 4 were as follows:

1. Substitute processes in repair design must be approved by the OEM or by a DER.

2. Approved repair design must have the goal of producing a sound and durable bond, combined with nondestructive testing or proof testing.

5.2 SCENARIO

During an approach, a passenger looked out a window and observed severe damage to an outboard flap. Upon landing, it was discovered that approximately 80% of the trailing edge wedge assembly was missing. Investigation revealed that the skins had disbonded from the spar, which had not been adequately treated in the original bond process performed at the MRO (figure 11). After assessment of the defective assembly for damage, it was discovered that the primer had stuck to the adhesive and separated with the skins, leaving a scuff sanded spar surface exposed.

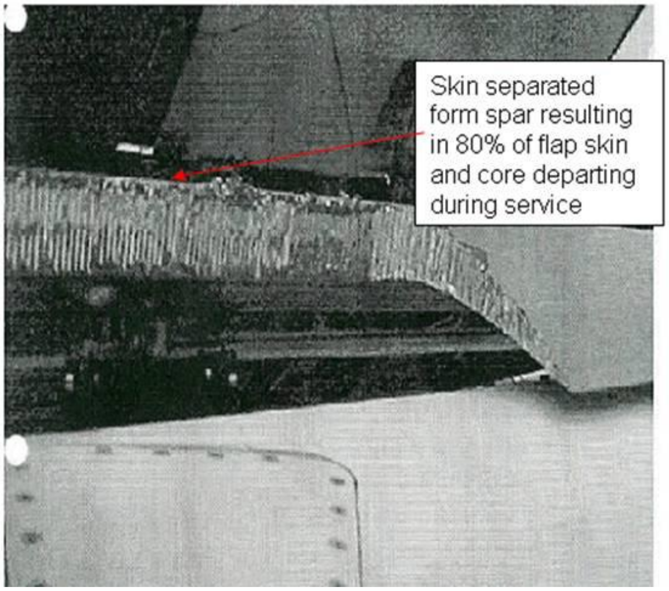

Figure 11. Disbonding Between Skin and Spar Following Repair

Prior to this inflight incident, the airline sent the outboard flap assembly to a contract MRO who had listed the flap assembly in its capability list for the required skin and core replacement repairs.

The Authorized Release Certificate FAA Form 8130-3, Airworthiness Approval Tag, which accompanied the repaired assembly, was reviewed for procedures used by the repair station to return the part to service. All documentation from the repair station was found to be in accordance with FAA DER procedures for general structures part teardown and repair. The approved repair design procedure allowed a substitute surface preparation procedure, which included scuff sanding, chromate conversion coating (CCC), and adhesive primer application in place of phosphoric acid anodizing (PAA) surface treatment, which was an approved process of the OEM when PAA is not practical.

The MRO removed all skins, doublers, and honeycomb core from the flap assembly for repair and used the procedure approved for other assemblies per 8130-3. They used the CCC procedure for the repair—a procedure that had been used on a flap from a similar commercial transport aircraft in the past. The repair instructions in the SRM were generic for all structures and were not authorized for any specific component or assembly.

The MRO had implemented the substitute procedure that allowed the technician to scuff sand, perform CCC, and apply adhesive primer to areas of the original OEM-built components that were previously anodized with phosphoric acid. These areas consisted of the entire spar and the upper and lower skin mating flanges where the skins were bonded to the spar by using the hot bond autoclave process. The repair procedure was not approved by the OEM for this assembly repair scenario.

6. CASE STUDY 5—NOSE COWLING

6.1 KEY ISSUES

The key issues found for case study 5 were as follows:

- Visual appearance is not a good indicator of structural.
- Inadequate technician training to recognize unapproved or unacceptable practices.
- Not following guidance from authorized documentation, such as the OEM SRM, should be followed.
- Appropriate safety management procedures to ensure checks and balances in a team environment are needed.

6.2 BACKGROUND

With its exposed location, an engine nose cowl often suffers foreign-object damage, such as bird strikes, which can take an aircraft out of service while the damage is repaired. A typical nose cowling is shown in figure 12.

Figure 12. Typical Nose Cowl Dispositioned for Repair

6.3 SCENARIO

An airline operator had authorized a repair on the inner acoustic barrel of a commercial transport cowling by an outside maintenance contractor. Following this repair, the vendor returned the nose cowlings, including the required FAA Form 8130-3, which stated that the repair was in compliance with the OEM SRM.

After two months of service, a routine maintenance check by airline technicians revealed that the wire mesh bonded to the nose cowl inner barrel acoustic skin had disbonded in several locations, which initiated further evaluation by the airlines' maintenance facility.

After partial disassembly, the inner barrel appeared visually to be correct (figure 13), but experienced technicians recommended further evaluation of the nose cowl assembly. During this evaluation, airline repair technicians and inspectors noticed an irregular repair to the inner barrel back skin. Further investigation revealed that poor workmanship and a lack of adherence to proper repair procedures were the causes for the significant underlying discrepancies.

Figure 13. Inner Barrel Prior to Disassembly and Further Investigation

The following discrepancies were observed:

1. After removing access panels' outer barrel skins, it was observed that the repair to the inner barrel exceeded the circumference limitation of 25 inches imposed by the OEM's SRM. This was not annotated in FAA Form 8130-3, nor was the repair accomplished with approved data that should have been required for exceeding the SRM limitations.

2. The outer skins were removed for examination, revealing further issues:

   a. There were double-drilled attach holes that were partially filled with sealant/adhesive to plug old holes (figure 14). Glass fabric was applied to one side of the sealant/adhesive to create an aesthetically pleasing finish. It appeared that the vendor repair station had double-drilled holes and had filled these holes with paste adhesive to hide the double drilling.

Figure 14. Improper Drilling Workmanship and Failure to Follow Correct Repair Procedure

   b. Large cracks had been covered with sealant at the edges where erosion or sanding had caused outer-ply damage (figure 15). This damage was extended completely through all layers of carbon.

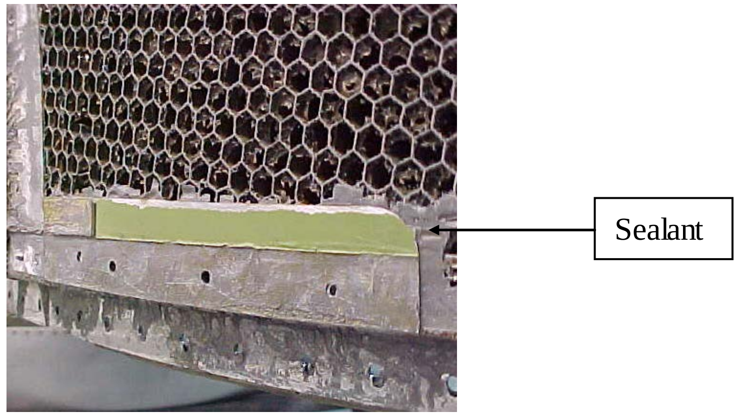

Figure 15. Example of Improper Use of Sealant During Repair

c. Fastener scoring damage at attachment locations was extensive (figure 16).

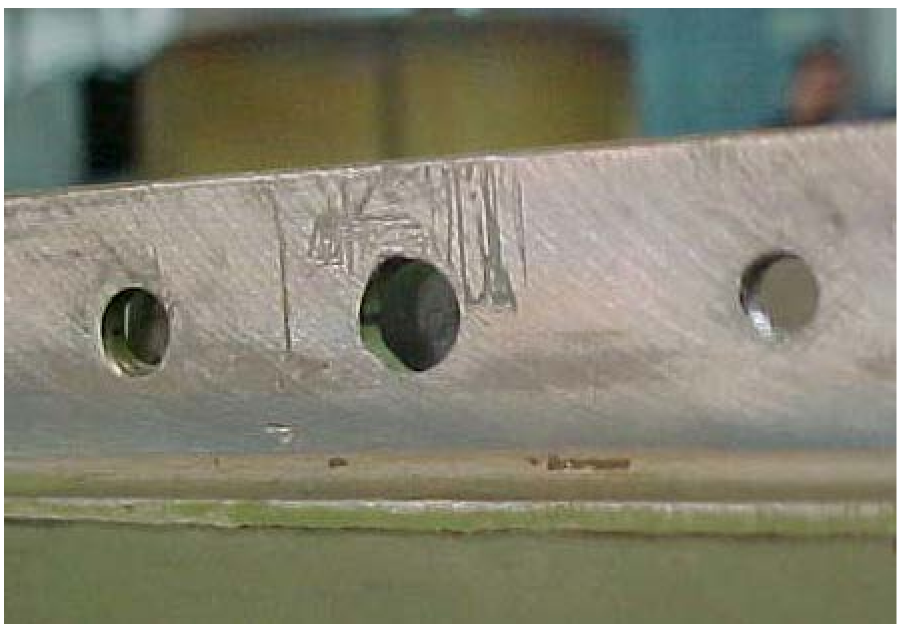

Figure 16. Fastener Scoring Damage

A subsequent vendor audit of procedure and policy related to the nose cowling identified numerous other discrepancies. The nose cowl part was deemed to be a complete loss because of the numerous double-drilled holes.

7. CONCLUSIONS

The five documented scenarios of improper and faulty composite field repairs identified root causes, which included inadequate technician training, incorrect composite repair techniques, and violation of proper procedures. The key issues found in each case that led to the faulty repairs are as follows:

- Case Study 1—Overhauled Flap Assembly

  - Tooling had incorrect contours.
  - Repair outside of Structural Repair Manual (SRM) limitations.
  - Incorrect hot bonder technique.

- Case Study 2—Slat Assembly

  - Tooling had incorrect contours.
  - Repair based on superseded flag note.

- Case Study 3—Inboard Flap Honeycomb Repair

  - Repair station did not use bond-line confirmation as required by operator engineering.

  - Excessive bond thicknesses suggested incorrect tool contour.

  - Core was damaged from overheating.

  - Honeycomb replacement core was distorted.

- Case Study 4—Adhesive Bonding and Surface Preparation

  - An alternative procedure, chromate conversion coating (CCC), was used without specific work instructions instead of the approved PAA surface treatment.

  - The CCC procedure followed, which was defined on a similar part (and from a different aircraft).

- Case Study 5—Nose Cowl

  - Repair was outside of SRM limitations.

  - Improper repair technique was used as well as materials that appeared to conceal discrepancies.

The documented case studies identified root causes, which included inadequate technician training, incorrect composite repair techniques, and violation of proper procedures. Other related underlying contributing factors included the tendency of some practitioners to:

- Equate the quality of surface aesthetics with structural integrity.

- Provide quicker and more economic repair services by third parties through unapproved shortcuts and techniques.

- Apply approved repair processes outside the limitations that are specified by the SRM.

Common nonconformance issues among the case studies include:

- Repairs approved for one specific application that were used on a different application.

- Implementation of repairs that were outside limitations imposed by authorized documentation, such as the SRM.

- Improper repair design analysis.

- Improper repair techniques.

- Lack of proper tools.

In many cases, these issues could have been limited by increasing practitioner awareness through training regarding the importance of proper techniques, procedures, and processes as a basis for assuring structural integrity and conformance to aircraft type design by the repair design and its implementation. Specifically, proper training in the use, placement, and implementation of cure equipment, such as a hot bonder, heat and insulation blankets, and thermocouples, is essential to achieving a quality repair. Training should enable repair technicians to recognize unapproved or unacceptable practices. Technicians should also be aware of what the accurate tooling practices are that allow for duplication of the original part contour.

The case studies have been used to illustrate safety management issues in a variety of forums:

- Presentations by regulatory agencies to public audiences to emphasize safety management principles and need for guidance.

- Global composite repair working groups, such as the Commercial Aircraft Composite Repair Committee, with a particular emphasis on repairs implemented outside of SEM limitations.

- Incorporation of case studies in Revision G of the Composite Materials Handbook 17 chapter on safety management as actual illustrations.

- Use of case studies to enhance learning experiences.

Each of the case studies provides an excellent means of communicating root causes for inadequate safety management. One of the primary lessons is that safety management is a blend of nonconformance issues, including team interactions, process understanding, and skills.

With regard to curriculum-development initiatives, these case studies have been used to create discussion forums by which an instructor uses a questioning technique among students to allow discovery of specific teaching points. Use of actual scenarios provides further meaning and significance to the learning experience. The five case studies also illustrate common themes among nonconforming repairs.

8. REFERENCES

1. Davis, M, "Safety Risks in Applying Damage Tolerance Analysis to Certification of Adhesively Bonded Structures and Joints," *Aircraft Airworthiness and Sustainment Conference*, Brisbane, Australia, July 26-28, 2011.

2. Herrington, T. (2012, March 29). Cabin Ops Support Engineering. (S. Richter, Interviewer)

3. Black, S., "Experienced Aerospace Manufacturer Relies on Proven Methods," *High-Performance Composites*, March 1, 2003.