



AEROSPACE INFORMATION REPORT

AIR6292™

Issued

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Guidelines for Bonded Repair Process Evaluation of Fiber Reinforced Composite Structure

RATIONALE

This document is intended to satisfy the need for a checklist of best practices in implementation of tooling, process steps, and quality controls that help to make sure that a previously substantiated repair design and process requirements are met.

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1. SCOPE

This SAE Aerospace Information Report (AIR) is a process verification guide for evaluating implementation of key factors in repair of fiber reinforced composite bonded parts or assemblies in a repair shop, hangar, or on-wing environment. This guide is to be used in conjunction with a regulatory approved and substantiated repair and is intended to promote consistency and reliability.

1.1 Purpose

This AIR is intended to be used as a guide for regulatory and Customer personnel during the evaluation process of a substantiated repair submitted to the aforementioned parties by a repair station acting on behalf of a Customer to carry out a repair to fiber reinforced composite bonded structure. This AIR is also intended to be used as a supplement to AS7118 during an audit to evaluate repair station processes.

This document may be used as a reference for a Customer to understand some key considerations to be taken into account during the repair process. This document is intended for shop level repairs; however, all the procedures given within this document can also be used to evaluate repairs accomplished on-wing. This document is **NOT** intended to be a design handbook for repair stations that wish to substantiate repairs that extend beyond the size limits or deviate from the repair instructions of an OEM-approved repair manual, such as a Component Maintenance Manual (CMM), Structural Repair Manual (SRM), Aircraft Maintenance Manual (AMM), etc.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR4844	Composites and Metal Bonding Glossary
AIR4938	Composite and Bonded Structure Technician/Specialist Training Document
AIR5278	Composite and Bonded Structure Engineers: Training Document
AIR5367	Machining of Composite Materials, Components and Structures
AIR5431	Repair Tooling
AIR6291	Guidelines for Repair Process Evaluation of Aluminum Bonded Structure
AIR6825	Identification and Assessment for Damage to Composite Aircraft Structures Training Document
ARP4916	Masking and Cleaning of Epoxy and Polyester Matrix Thermosetting Composite Materials
ARP4977	Drying of Thermosetting Composite Materials
ARP4991	Core Restoration of Thermosetting Composite Components
ARP5089	Composite Repair NDT/NDI Handbook
ARP5143	Vacuum Bagging of Thermosetting Composite and Metalbond Repairs

ARP5144	Heat Application for Thermosetting Resin Curing
ARP5256	Mixing Resins, Adhesives, and Potting Compounds
ARP5319	Impregnation of Dry Fabric and Ply Lay-Up
AE-27	Design for Durable, Repairable, and Maintainable Aircraft Composites

Armstrong, K.B., Cole, W., and Bevan, G. (2005). *Care and repair of advanced composites* (2nd ed.). SAE International.

2.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 20-107B	Composite Aircraft Structure
AC 43-14	Maintenance of Weather Radar Radomes
AC 43-214A	Repairs and Alterations to Composite and Bonded Aircraft Structure
DOT/FAA/AR-03/53	Effects of Surface Preparation on Long-Term Durability of Adhesively Bonded Composite Joints
DOT/FAA/AR-06/28	The Effect of Peel-Ply Surface Preparation Variables on Bond Quality
DOT/FAA/TC-14/26	Advanced Fourier Transfer Infrared Spectroscopy for Analyzing Damage in Aircraft Composites

2.3 PRI Publications

Available from Performance Review Institute, 161 Thorn Hill Road, Warrendale, PA 15086-7527, Tel: 724-772-1616, <https://www.p-r-i.org>.

PRI AC7118/1	NADCAP Requirements for Prepreg/Adhesive Bonding
PRI AC7118/3	NADCAP Requirements for Core Processing

2.4 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-213	Minimum Operational Performance Standards for Nose-Mounted Radomes
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2.5 Other Publications

AMC 20-29	Composite Aircraft Structure
PS-AIR-20-130-01	Bonded Repair Size Limits Policy Statement
PS-ANM-25-20	High Energy Wide Area Blunt Impact Policy Statement

3. DEFINITIONS

Refer to AIR4844 for a more complete composite and metal bonding glossary. New terms that appear in this document are defined below:

ASSEMBLY JIG (AJ): When assembling fittings, leading edge skins, latches, or any other part that requires alignment to a theoretical datum, such as a hinge axis or a contour line, an AJ may be necessary equipment during accomplishment of a repair.

AMM: Aircraft Maintenance Manual provided by aircraft manufacturers. Sometimes referred to as “MM” or “OEM MM.”

ASSEMBLY MANDREL (ASM): An ASM is any intermediate tool used during original manufacture or during repair to structure that does not have critical effect on the integrity of the final assembly or any of its subcomponent details. It is sometimes necessary to use a lightweight tool that is neither dimensionally controlled nor dimension tolerance critical. Sometimes referred to as a “shop aid.”

BACKING MATERIAL: Material used to support and protect film adhesives and prepreg during storage and kitting prior to layup. Backing materials may be release-coated paper products or plastic films. Backing materials provide a barrier to prevent the adhesive and prepreg from adhering to itself during storage and protect and support the adhesive and prepreg during handling. Also known as backing paper, backing film, separator sheet, carrier sheet, or release film.

BONDED ASSEMBLY JIG (BAJ): Tooling used to define and/or maintain appropriate contour of the part being manufactured or repaired during high pressure and temperature cycles (autoclave or vacuum assisted oven cure).

CONTROLLED CONTAMINATION AREA (CCA): An area that ensures levels of dirt, dust, oils, lubricants, and other containments are controlled for acceptable structural bonding. It may also be referred to as a “clean room” in a shop or factory environment.

COMPONENT MAINTENANCE MANUAL (CMM): Document which details the way in which maintenance tasks shall be accomplished for a specific component. Sometimes referred to as “MM” or “OEM MM.”

CTE: Coefficient of Thermal Expansion

CUSTOMER: The Customer may be an owner or an operator of the airplane, or the Customer may be a holder of a spare component. When the component is being repaired at an outside maintenance facility, the Customer is responsible for regulatory oversight of the repair station. A repair station must have a regulatory approved certificate. Repairs are approved and coordinated with the OEM or submitted to the regulatory agency whenever repairs are accomplished outside of an OEM provided repair documentation (i.e., CMM, SRM, or AMM).

EME: Electromagnetic Effects

EMH: Electromagnetic Hazards

ENGINEERING: Organizations or individuals responsible for providing part-specific repair documentation, and all other supporting documentation such as material and process specification, tool design, inspection criteria, etc. Engineering departments at airlines also have the responsibility to determine acceptability of repair documents and of repaired parts to ensure there is no conflict with the airline's maintenance program, configuration, reliability program, and interactions with systems. Engineering is responsible for coordinating with OEM, Regulatory Authorities, or other experts when repairs are outside their area of expertise and/or previous experience. Engineering has the responsibility to make sure that the repair as correctly implemented satisfies all regulations for airworthiness.

FIRST ARTICLE INSPECTION (FAI): A planned, complete, independent, and documented inspection of the first viable part and verification process to ensure that prescribed processes have produced an item conforming to engineering requirements.

FATIGUE CRITICAL STRUCTURE (FCS): Airplane structure that is susceptible to fatigue cracking, which could contribute to a catastrophic failure. Also includes both Fatigue Critical Baseline Structure (FCBS) as defined by the OEM and Fatigue Critical Altered Structure (FCAS) as defined by the operator.

FOURIER TRANSFORM INFRARED (FTIR): A technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid, or gas. An FTIR spectrometer collects high-resolution spectral data over a wide spectral range. Used in composites to detect surface contamination and degree of cure of the surface of the composite.

LSP: Lightning Strike Protection

MM: AMM or CMM

NON-DESTRUCTIVE INSPECTION (NDI): Instrumented inspection techniques that do not require personnel qualification and certification in accordance with applicable technical standards for non-destructive testing personnel. Examples include tap test, automated tap test, and handheld “go-no-go” ultrasonic instruments.

NON-DESTRUCTIVE TESTING (NDT): Instrumented inspection techniques that require personnel qualification and certification in accordance with accepted standards for non-destructive testing personnel, and that is not being considered as Non-Destructive Inspection (NDI, see NDI definition). Examples include handheld PE, TTU, X-ray, thermography, eddy current, and Fourier-transform infrared spectroscopy (FTIR).

NHA: Next Higher Assembly

NTM: Non-Destructive Testing Manual

OEM: Original Equipment Manufacturer

OML: Outer Mold Line

PAA: Phosphoric Acid Anodize

PULSE ECHO (PE): Ultrasonic inspection technique where signal is transmitted and received by the same transducer. Useful when there is access to only one side of a part.

PRINCIPAL STRUCTURAL ELEMENT (PSE): An element that contributes significantly to the carrying of flight, ground, or pressurization loads, and whose integrity is essential in maintaining the overall integrity of the airplane. PSE structures are defined by the OEM.

QUALIFIED BONDING PROCESS: The characterization and control of specific parameters used when surface preparation is required to at least one of the structural interfaces prior to bonding. A Qualified Bonding Process is documented after demonstrating repeatable and reliable processing steps. Qualified Bonding Process entails both development and documentation of the process, and demonstration that the process can be executed by the user. Refer to AC 20-107B/AMC 20-29, 6c., for guidance.

QUALIFIED BONDING SYSTEM: The specific combination of substrate, adhesive, type of surface preparation, and cure parameters controlled and validated under a Qualified Bonding Process.

QUALITY: Organizations or individuals responsible for either Quality Assurance (QA) and/or Quality Control (QC) functions.

QA functions typically make sure systems and procedures are in place to ensure all organizations perform as required by documents and policies. QA functions are responsible for making sure documents are up-to-date, repair technicians are current on training, and equipment is calibrated. QA functions are also responsible for identifying any corrective action that may be required if a defect is identified during a repair.

QC functions are responsible for testing and inspection of products to make sure that the products meet the requirements of the Repair Document. QC checks for defects during the manufacture or repair process. QC methods may include controlled tooling, jigs, NDT, raw material controls, training, qualifications, etc. Quality has the responsibility to make sure that the repair is correctly implemented to meet airworthiness requirements.

REPAIR DOCUMENT: An engineering repair authority that has been approved by the Customer to perform work on a specific part or assembly. An SRM provided by a Customer to a repair station is an example of a Repair Document, as is any other regulatory approved engineering data listed as an approved manual or manual supplement that is maintained by the Customer in accordance with its regulatory approved Operations Specification. A Repair Document may include references to other external documents or specifications that control processes, materials, shop practices, etc. Comply with all external specification references, which are considered part of the Repair Document.

SDR: Service Difficulty Report

SRM: Structural Repair Manual

SSI: Structural Significant Item, as determined by the OEM.

TIME AND TEMPERATURE SENSITIVE (TATS): Materials such as pre-impregnated tapes and fabrics and film adhesive that are sensitive to both time and temperature.

THERMAL PROFILE: A set of time-temperature data typically associated with the measurement of temperatures on the part and/or repair during the cure cycle.

THERMAL MAP: The thermal map is used to record the thermocouple placement and insulation placement prior to curing the repair to assure thermal uniformity and meeting process requirements.

THERMAL MAPPING: Process of identifying the thermal behavior of the part and/or tool surface based on thermal mass differences in the part, variable thermal mass in the support tooling, or differences in material thermal conductivity.

THERMAL SURVEY: The process of applying the intended cure cycle to the repair area and evaluating the placement of thermocouples and insulation to ensure the repair meets cure cycle requirements. Used to validate the thermal mapping. Thermal surveys may require the use of a surrogate patch and additional thermocouples under the repair patch.

THERMAL COMPLEXITY: A measure of thermal management required as determined by the type of heat source, the number of repair plies, and the type and number of heat sinks present.

THERMOCOUPLE PLACEMENT DIAGRAM: A sketch or graphic which identifies each thermocouple wire on a particular area or heat zone of the repair.

THERMOGRAPHY: Infrared thermography (IRT), thermal video, and/or thermal imaging is a process where a thermal camera captures and creates an image of an object by using infrared radiation emitted from the object. Used in composites to detect fluid ingress in sandwich panels as well as delamination.

THROUGH TRANSMISSION ULTRASONICS (TTU): Ultrasonic inspection technique where signal is transmitted and received by transducers on opposite sides of the part.

4. GENERAL

4.1 Overview

The following sections define the damage evaluation, preparation, repair, post repair evaluation, and finishing steps that should occur for any repair to composite bonded structure. The procedures contained within this section follow the guidelines and recommendations in FAA AC 43-214A. Examples, figures, and best practices are incorporated in each of the sections which illustrate the intent of the step being described. The illustrations are representative and do not describe all conditions.

A companion document, AIR6291, contains process flows and key process steps for metal bond repair. Processes and key process steps in AIR6291 may be applicable to fiber reinforced composite repair and are referenced in this document where appropriate.

This document is complementary to the technical assessments specified in Nadcap** AC7118 AUDIT CRITERIA FOR COMPOSITES, available from Performance Review Institute (PRI). The Nadcap document is used by OEMs primarily for manufacturing audits. Contents are applicable to the repair process.

***Nadcap* (formerly *NADCAP*, the National Aerospace and Defense Contractors Accreditation Program) is a global cooperative accreditation program for aerospace engineering, defense, and related industries.

4.2 Process Flows

4.2.1 Process Flows Overview

The flowchart figures included in this document describe an overview of all steps that should occur during accomplishment of a repair to composite bonded structure. Due to the variety in composite construction and repair circumstances, the process flows provided in this document may not be directly applicable. The user is advised to adjust the process steps for their specific situation. Detailed descriptions of each step are referenced by paragraph number within the process flow diagrams.

4.2.2 Process Flows Role of Quality Personnel

Whenever process flow diagrams indicate that Quality personnel be utilized, quality checks should be accomplished by an individual which is different from the party who is directly responsible for accomplishing the repair. This will assure that an independent source will verify conformance to approved materials and processes. Quality check personnel should be knowledgeable about the materials and processes being implemented.

4.2.3 Roles and Responsibilities Indicator

Indications have been made beside each step as to which type of personnel may be needed, as a resource, to complete each task. See Figure 1. These indications are not intended to be requirements; however, it is intended to aid in resource planning to facilitate the process flow. Different repair stations may vary in how their organization distributes responsibility; therefore, adherence to any particular designation shown in the following process flowcharts may not match each organization's structure.

M	General Mechanic / Shop Technician.
I	Inspector / NDT Technician
T	Job-Specific Trained Mechanic / Specialist
Q	Shop Inspector / QA / Management
P	Purchasing / Supply Chain / Logistics

Figure 1 - Role indicator key for major flowchart sections

4.3 Preparation Steps Prior to Repair Accomplishment

The following section recommends steps for the identification, removal, and preparation of a repair part. This section includes the procedures to make sure adequate facilities to carry out a composite repair. Preparation steps must be followed prior to accomplishing the repair in order to validate the repair procedure. The following flowchart (see Figure 2) is intended for initial planning purposes.

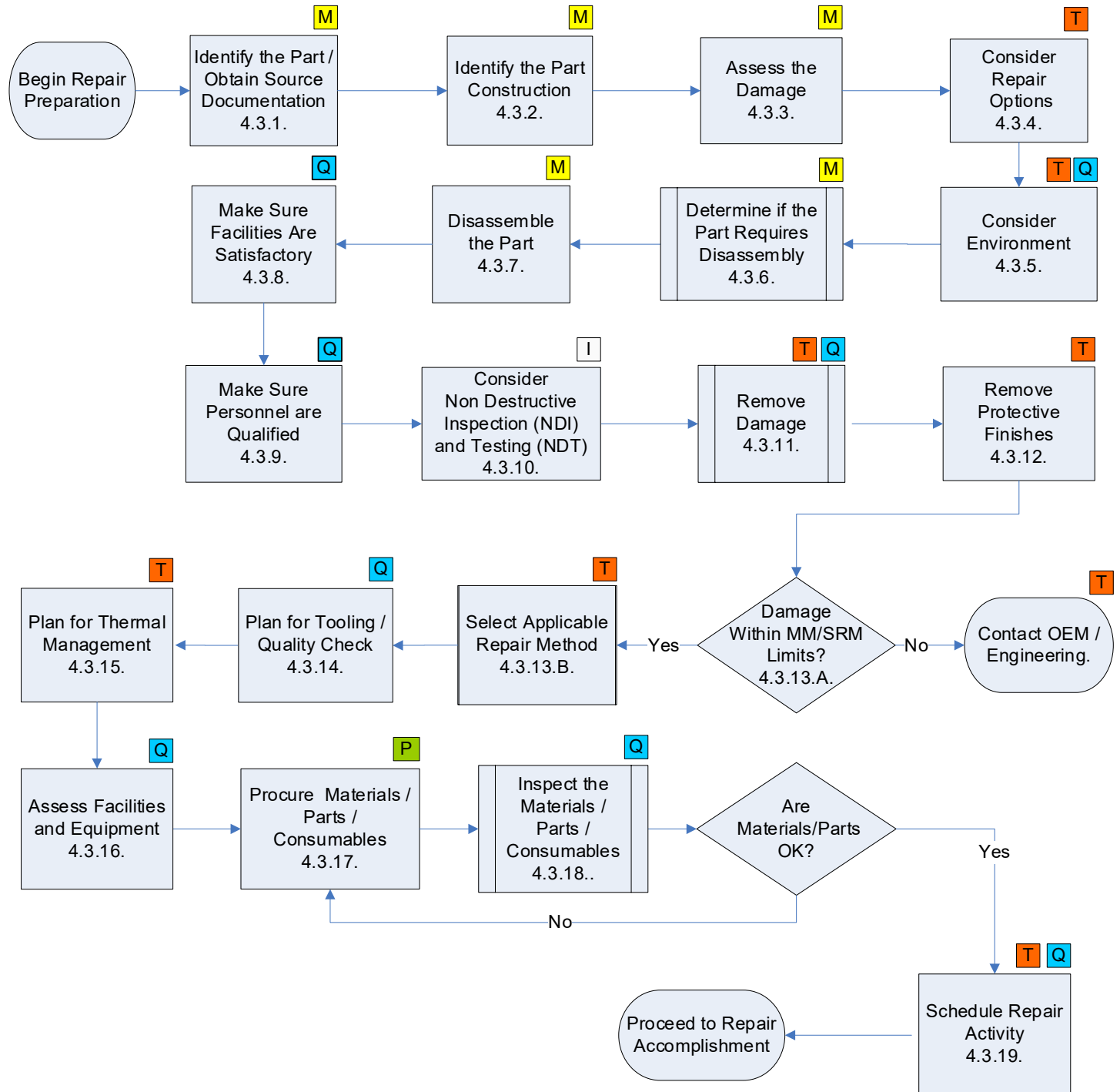


Figure 2 - Repair preparation decision flow

4.3.1 Identify Part and Obtain Source Documentation

- A. Identify the damaged structure by part number and corresponding limitations for repair as specified in authorized source documentation, such as the OEM SRM. Make sure that the manual(s) being used to identify the part has been supplied by the Customer and is applicable for the aircraft serial number. If working on a top-level assembly that is already removed from the aircraft, make sure that the manual is applicable to the part number and serial number of the Next Higher Assembly (NHA) component for which the damage is identified.

- (1) Identify previous repairs which may affect repair disposition of the part to be repaired.

NOTE: Previous bonded repairs may not be immediately apparent at this stage of the process, as they may be hidden or covered by protective finishes.

- (2) If no manual is available that is adequate enough to identify the damaged component, contact the Original Equipment Manufacturer (OEM) and request data on proper identification of the structure being assessed.

- (3) The manuals or OEM data should include the following:

- (a) Inspection procedures needed to disposition damage.
- (b) Allowable damage and repair size limits.
- (c) Repair designs and processes for the specified damage sizes and locations described for a given structure.

NOTE: It is a regulatory requirement that component maintenance and repair manuals and data match the component part number.

4.3.2 Identify the Part Construction

- A. Using the Customer supplied maintenance manual, repair manual, or other applicable OEM sources, such as Engineering drawings or written correspondence with the OEM, identify the materials of the structure that are damaged or are coincident to the damage site. A general mechanic or shop technician will usually be responsible for identifying part construction. Some identifying tasks may require additional composite specific technical knowledge. AIR6825 provides guidance for training for general mechanics or shop technicians to conduct the assessment.

- (1) Information to obtain may include but is not limited to the following:

- (a) Skin panel and substructure part numbers that are damaged.
- (b) Part numbers for honeycomb core, including material identification, as follows: metallic (alloy type/material type) or nonmetallic (foam, aramid, or fiberglass), perforated, foil/paper/wall thickness, cell shape, cell width, nominal density.
- (c) Part numbers and material identification of coincident structure, such as spars, fittings, dust covers, seals, and any other features that may be coincident to the damage site.

- (2) Determine construction type (laminate or sandwich). Identify bond lines for co-cured or pre-cured structure.

NOTE 1: The type of NDI or NDT technique to be used for damage assessment on sandwich structure requires facesheet thickness and part construction. Follow the supplied maintenance manual, repair manual, or other applicable OEM sources.

NOTE 2: The type of NDI or NDT technique to be used for damage assessment on laminate structures requires knowledge whether there are bond lines (e.g., co-cured, pre-cured) and changes in part thickness. Follow the supplied maintenance manual, repair manual, or other applicable OEM sources.

(3) Identify the composite materials and adhesives used in the construction. Check against the Repair Document for repair materials that are applicable and available. The decision to process a repair may depend on the initial assessment of the repair materials and whether they can be procured quickly and for acceptable costs.

- B. Using the Customer supplied manual(s), determine if there are acoustic, weight, and/or balance requirements/limits considerations for the structure being assessed. It may become necessary to calculate or measure a new weight, acoustic blockage, and/or balance for the NHA after a repair is accomplished.

NOTE: If NHA requirements exist for weight and/or balance, identify a placard on the NHA that can help to determine previous repair weight and/or balance changes and how much additional rework can be done to the NHA before maximum rework limits are exceeded. Procedurally, this may greatly influence how and if the structure will be repaired. This step should be accomplished as early in the process as possible.

- C. Regulatory actions may need coordination with the Customer before continuing with the repair. These regulatory actions are typically related to the type or category of structure. The OEM manuals will define the category of structure.

NOTE: Some customers such as airlines have specific unique actions that are required, per their Operations Specification, when working on types of structures such as Primary Structure, PSE, SSI, or FCS. Whenever a part being repaired is any of these categories, the airline is notified so that, if necessary, specific instructions can be given to the repair station on how to comply with the airline's Operation Specification requirements.

EXAMPLE 4.3.2.C.(1): An airline may have special Service Difficulty Report (SDR) submission requirements for PSE, SSI, and Primary Structure, depending on the level of repair being accomplished.

EXAMPLE 4.3.2.C.(2): Many airlines have specific repair identification procedures and possible follow-up actions that are required on repairs to FCS structure.

- (1) The airline must have adequate information to identify a repair that might affect these types or categories of structure and that the final regulatory approved work documentation (such as an FAA 8130-3 form or equivalent) contains any required continued airworthiness instructions to the airline.

- D. A customer may have additional requirements which must be considered and/or that may need to be completed before continuing with the repair. These requirements may be related to items such as placards, paint, labeling, mod status, and service bulletin status incorporation.
- E. Identify acoustic requirements which may exist in the area of repair. Determine if the repair will be outside the acoustic limits given in the Repair Document. It may be necessary to replace rather than repair the part if acoustic limits will be exceeded.
- F. Identify whether the part has features for EME protection in the area of repair. Determine whether restoration of the EME protection is required.

4.3.3 Assess the Damage

- A. Using maintenance manual(s) and other approved data, determine the damage assessment procedures and make sure that these procedures are applicable to the part number and specific structural elements that are damaged. If removal of the structure from the aircraft or from any NHA will be required or anticipated, make sure that all applicable Customer supplied maintenance manuals are in hand to accomplish these procedures before proceeding to the next steps.

NOTE: When assessing impact damage to external skin, check the maintenance manual for the presence of substructure that could have also been damaged in the incident. There is a type of damage that leaves little to no visible evidence but may result in extensive internal damage. This type of damage is known as High Energy Wide Area Blunt Impact (HEWABI) (refer to PS-ANM-25-20). This type of damage requires an extensive internal assessment as well.

- B. If there are any specific tools or equipment that will be required to perform any removal procedures, procure these in advance before proceeding to the next steps. Examples might include shoring equipment, holding fixtures/slides, overhead cranes, jacks, alignment fixtures, or any other equipment that is non-standard for performing general maintenance activities. Refer to AIR5431 for information related to the use of support tooling for composite repair processes. If appropriate measures are taken to temporarily restore contour in the damaged area, the part may be able to be used to make a splash tool; however, the technician will need to determine if the damaged component is suitable for fabricating the tool. Before removing damage, it should be considered whether the part structural rigidity would change the contour as the damage is removed, which would then make the part not acceptable to use for tool development. The part should be held during the disassembly and repair by a frame or temporary tooling to make sure the contour and interface points are retained. An example is shown in Figure 3.

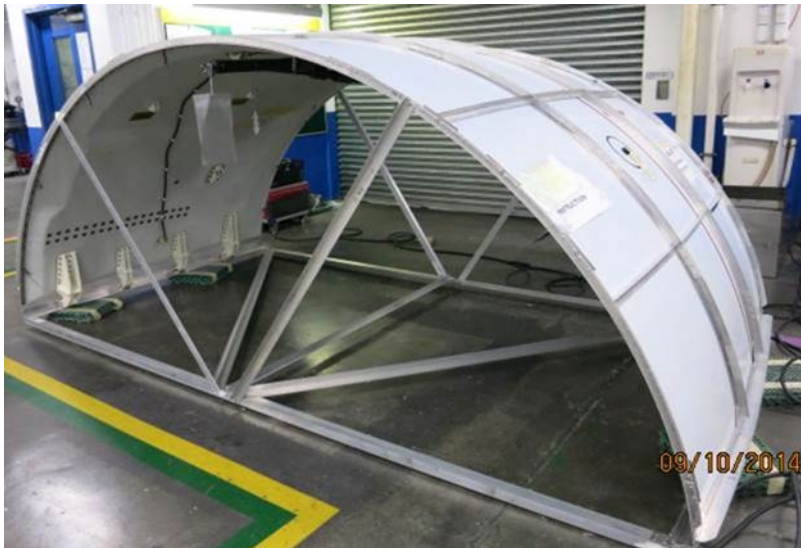


Figure 3 - Frame tooling to stabilize part

- C. Composite parts may require special techniques to assess the damage. Damage may include the following:
- (1) Heat Damage - Visually inspect for any charred or darkened areas and burn marks on the surfaces and edges of the part, blisters, or bubbles on surface finishes or on the surface and edges of the part. Visually inspect for burn through areas or resin charred areas. Tap test and NDT for internal damage that extends beyond or is not detectable by visual means. FTIR NDT methods can be used to identify where the matrix properties have been affected by heat damage. Refer to DOT/FAA/TC-14/26, which describes the effectiveness of FTIR for detecting thermal induced damage in aircraft composites.
 - (2) Fluid Contamination/Absorption - Fluids may be comprised of water, hydraulic fluids, fuel, oil, or lavatory waste. It is important to distinguish the type of fluid that may have been absorbed or contaminated the structure. Moisture meters may be used to detect absorption, as well as an apparent swelling or spongy response to probing. Procedures for non-destructive inspection and for moisture removal and drying are provided in 4.4.7.
 - (a) Water may be removed by dehydrating the area. Dyes or staining from fluid contamination may remain after partial evaporation indicating previous contamination and should be completely removed.
 - (b) Oils (including hydraulic fluid such as Skydrol) and fuel will require removal by solvent or other means as those fluids will not evaporate completely and leave a residue that will compromise bond strength.
 - (c) For all fluid contamination, the type should be determined to evaluate the compatibility with existing and repair materials, and to choose the appropriate removal method or if complete removal of the contaminated materials is required. Any cleaning solutions, chemicals, or solvents must be compatible with the baseline materials and preparations for the repair materials. Consult the Repair Document or contact the OEM for guidance.

CAUTION: Extensive fluid contamination uncovered during the damage assessment may affect the size of the repair, the available repair cure-temperature options, as well as repair drying. The intensive drying cycles may be required, or the core may need to be replaced in its entirety.

- (3) Lightning Strike - Visually inspect for any pitting, rupture, or burn markings on the structure. This may include fiber-matrices that have been overheated, causing fibers to separate and show as tow/yarns from the structure. Also look for possible lightening attach points evident by burn markings or any other fiber/resin distortion, and inspect for pitted fasteners, burn marks, and delamination. Tap test and NDT for internal damage that extends beyond or is not detectable by visual means. Lightning strike may also result in heat damage. See 4.3.3.C.(1).
- (4) Impact Damage - Damage may be visible on the surface through deformation of the outer plies or a dent or tear in the facesheet of sandwich structure. Often, the damage to the part extends well beyond the visual indications. Further inspection is required to determine the extent of the damage not only at the direct impact area but at load reaction substructure such as fuselage frames, or wing stringers and rib interface locations. This damage may extend some distance from the impact area. For example, a thrown landing gear tire tread may only leave an external indication from the impact as a scuff mark on the wing or horizontal stabilizer skin. As service experience has shown, internal structure may have extensive stringer and/or rib shear tie damage which is not detectable by an external inspection but can be easily detected with an internal visual inspection.
- (5) Abrasion - Damage will likely be visible on the surface through removal of surface finishes and outer plies. Further inspection is required to determine the extent of the damage as it may be also associated with additional damage types.
- (6) Propagation of Internal Defects - Large scale defects such as disbonds may be found by visual means if the outer surfaces have lifted. Tap testing may reveal additional delamination, but specific detailed NDI and NDT methods may be required to find smaller defects and the full extent of the damage to larger, more readily detectable defects.

NOTE: Composite parts use different NDI and NDT techniques which may be limited by the type of damage, and construction method. For example, reliability of tap test on facesheets depends upon damage size and facesheet thickness.

- D. Identify any previous/existing repairs to the structure being assessed. The proximity of an existing repair to current damage may be relevant in later steps when repair options are considered. The materials and procedures which were used to accomplish the previous repairs must be understood in case these details need to be coordinated with Engineering, OEM, and/or the Customer.

NOTE 1: It may be necessary to coordinate with the Customer to obtain historical information regarding the previous/existing repairs that are being assessed.

NOTE 2: The structural integrity of a previous repair which has been processed at a lower temperature cannot be known if the repair is exposed to a higher temperature during a subsequent repair. Previous repairs should be replaced or incorporated into the new repair if the cure temperature is not known.

- (1) Visual inspection should be the first step in determining if previous repairs or alterations have been accomplished in areas adjacent to the damaged area. Once surface finishes have been removed, look for boundaries of scarf patches, adhesive bond lines, fillers, and evidence of sanding on surface plies.
- (2) Tap testing the areas surrounding the damage may reveal core splices, filled core, and additional plies.
- (3) Pulse Echo Ultrasonic testing the areas surrounding the damage may reveal the small transition boundary areas between baseline structure and the previous repair.
- (4) Thermography and X-ray imaging of the areas surrounding the damage may reveal core splices, areas restored through potting compounds, or increased facesheet thickness from a previous repair.
- (5) For areas indicating prior repair, the maintenance records should be checked, and the prior repair documentation verified. The maintenance records are a key aspect in the determination of prior repairs and should be used in conjunction with various inspection methods to locate repairs which may be difficult to find. In addition, the production history, when available, should be reviewed for repairs, concessions, or nonconformities.
- (6) Accurate weight records of parts can reveal the presence of significant repairs which have added material to the structure.

- (7) In all cases, the inspection for previous repairs should extend beyond the boundary of the repair boundary of the current repair. Depending upon the heating method, the inspection should be conducted to evaluate whether the elevated temperature cure process may have an effect on existing repairs that are not compatible with the current repair process temperature.

NOTE: If a prior repair of lower cure temperature material is suspected in the affected area, the previous repair may need to be removed and become part of the damaged area to be repaired. Any repairs which use an oven or autoclave must take this into consideration.

- (8) Post repair NDT inspection of prior repair areas is required to ensure that the current repair process has not degraded the prior repairs.

4.3.4 Consider Repair Options

- A. An awareness of repair options in an early stage of the damage assessment/damage removal can be beneficial in minimizing the size and scope of the repair. The cleanup of the damage can depend on the notional repair design as specified in the draft Repair Document. If a local repair is being considered, it is beneficial to remove as little material as possible to stay within the size capabilities of the heat blanket and hot bonder. The damage removal should follow the notional repair design in an early stage by removing material in steps or scarfs according to the notional repair design. If the repair intent is to extend the repair to other features, to avoid a joint underneath a fitting, for example, the damage removal can be coarse in that direction. If the repair intent is a bolted repair or replacement of the whole skin, cleanup of the damage might not be required.

NOTE 1: It may be required to create a template in order to reposition features that are removed at later stages, such as recording the position of a fastener hole.

NOTE 2: It may be required to create support tooling to guarantee the original shape and contour of the part/component.

- B. The repair design can have additional steps which are convenient to perform at the damage removal stage while the component is still in a “dirty” environment; an example is removing the paint over the intended repair area.
- C. The Repair Document can contain requirements to NDI and NDT inspections and specification of NDI and NDT inspections to be performed during damage detection and the damage cleanup.
- D. Quality assurance of composite repairs is predominately done through control of the process. The process steps essential for quality control should be identified early in the repair process. The Repair Document may state that there are specific steps that need recording for quality assurance purposes, especially should there be features which cannot be inspected post repair. The choice of the repair option should consider the ability to control critical process steps, in particular, the thermal profile in the part throughout the cure and the ability to hold vacuum.

Composite repair in an oven or autoclave will generally provide controlled and uniform heat during the cure and the component can be fully vacuum bagged, which improves the reliability of the repair process.

CAUTION: Before specifying a 250 °F (120 °C) or higher cure in an oven or autoclave for a repair for an entire part, make sure that all previous repairs are capable of being exposed to this temperature. Low temperature cure repairs may be degraded by high temperature which may affect the strength of the component or the environmental durability for fluid ingress. See 4.3.6 for guidance on temperature exposure on finishes and sealants.

BEST PRACTICE: It is a standard practice to replace wet-layup repairs with prepreg when a component is going into autoclave or oven.

- E. Composite repair materials can have a low availability and/or long lead times to procure. Awareness of the available repair materials in combination with the required materials is needed. There could be requirements for compatibility among the repair materials, such as prepreg and film adhesive, between repair materials and baseline materials, and between repair materials and non-flying auxiliary materials, such as peel ply. A Qualified Bonding System will specify only materials that have been demonstrated compatible with each other for the repair process. Materials, even if similar, may not be substituted as the strength of the repair cannot be assured.

CAUTION: If it is required to use an alternative material, compatibility must be ensured with all other materials. The industry has experienced situations where incompatible materials have been used which have resulted in insufficient strength. Materials used in a bonding process must be qualified for use specific to the materials and the repair process. Adhesives, fibers and prepregs, and peel plies must be approved by Repair Document owner for compatibility.

- F. Based on the available information, options and the timescales of the options, and impact on the operational requirements, determine the approach to be taken. Operational requirements may favor a temporary solution instead of a permanent solution. Contact Engineering/OEM/Customer for Repair Document.

4.3.5 Consider Environment

- A. Repairs may be accomplished either on-airplane or in a shop environment. The decision where to conduct the repair is influenced by many factors, including the component damaged, the extent of damage, the facilities available, spare part availability, and the ease of part removal and reinstallation. Either option requires a controlled environment for temperature, humidity, and particulate control. The decision will depend upon the specific situation and judgment on whether a repair can be successfully completed taking into consideration environmental factors, such as periods of rain or high humidity, drafts over the repair, and high altitude.

- B. Advantages and disadvantages of on-airplane and shop repair are discussed below.

- (1) On-Airplane Repair - The advantages of repairing a component in place is there is no removal or reassembly/rigging required of the damaged and then repaired component. If the component is a permanently integrated part such as a fuselage skin panel or wing skin panel, on-airplane repair is the only option. A major disadvantage is that the equipment to accomplish the repair may be extensive and expensive. The accomplishment of the repair may be more difficult and is limited to heat blanket or hot box type repairs and require a local cell directly over the repair area. There may be a requirement to jack and shore the airplane during the repair. If hangar facilities are not available, large tents and scaffolding may be required to create an acceptable repair environment and to access the damaged area of the aircraft. The aircraft is also out of service the entire time to accomplish the repair.

CAUTION: If repairing a component on-airplane using a 350 °F repair material, make sure a local CCA limits air draft and the heat source chosen has the ability to provide enough energy to cure the repair to the repair specification requirements. See 4.3.15 for discussion on thermal management planning. See 4.4.9.B. for description of an on-airplane local CCA.

- (2) Shop Repair - This is the most often utilized environment chosen since most of the composite components are removable. Spares can be purchased or rented and installed on the aircraft to keep it in revenue service during the repair process. An advantage of repairing components in a shop environment is the availability of additional repair options, such as using heat blankets, oven, or autoclave cured repairs. The technician has access to better tooling, either permanent tools or the ability to produce local "splash" tools to maintain shapes and contours. Materials and environment are also better controlled in a shop CCA. Repair accomplishment is also more ergonomically desirable for the technician. Repair scheduling is often less of a concern. The disadvantage of a shop repair is transportation of the component between shop and aircraft, and the reinstallation and re-rigging of the component on the aircraft.

4.3.6 Determine if the Part Requires Disassembly

- A. Determine if the damaged structure should be removed from the aircraft before proceeding with any damage removal or repair procedures. For the repair, the damaged structure might need to be removed from the higher assembly (e.g., skin panel from a trailing edge wedge, control surface, or flap) or lower-level parts might need to be removed from structure (e.g., fittings, seals). Considerations that may drive the decision to remove the structure from the aircraft include, but are not limited to, the following (see Figure 4).

NOTE: Composite components may be of such size and part of the structural integrity that removal is not feasible (e.g., main wing box spar, fuselage pressure bulkhead). However, one should be aware of the issues listed in this section.

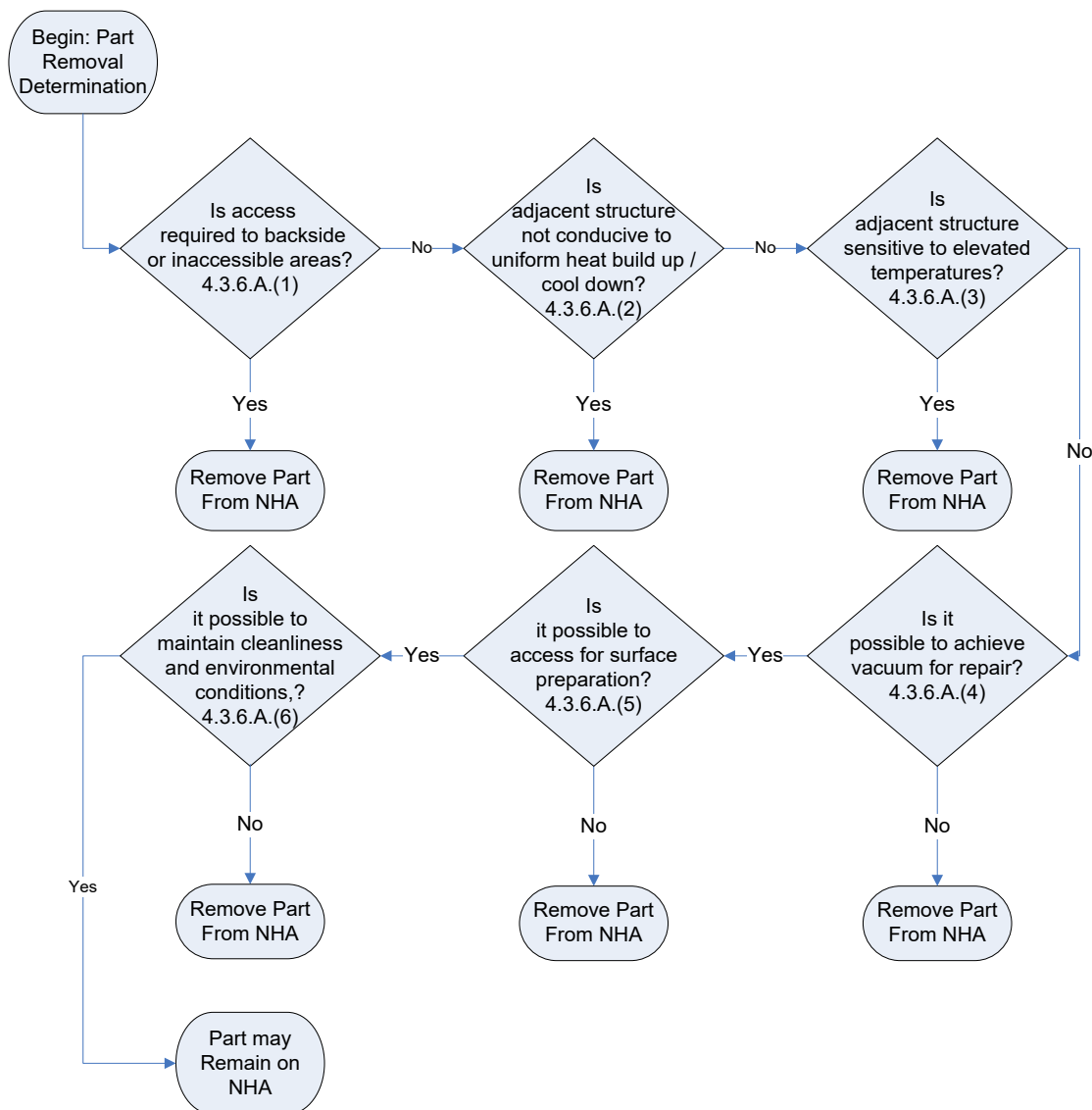


Figure 4 - Part removal decision flow

- (1) Access is required to areas that are inaccessible in the current situation to embody a repair or would encumber the repair technician's ability to perform all repair steps accurately to the required standard. For example, repairs may require access to the backside which might not be achievable with the damaged component installed. Removing the part from the next higher assembly can provide the required access. Similarly, fittings close to the damage may need to be removed if the repair will extend beneath the footprint of the fitting.

NOTE: Consider the complete repair process, including layup and vacuum bagging, when evaluating accessibility. Bagging and heating equipment could make limited space available; therefore, it is important to understand later steps with regard to space requirements.

- (2) Adjacent structure may not be conducive to uniform heat-up/cool-down rates during an elevated temperature repair cure cycle. An example of this might be performing a hot bond repair to a thin sandwich panel or plate that is adjacent to a large thermal mass, which act as a heat sink. Section 4.3.15 contains further discussion on planning for thermal management during a repair.

NOTE: Ribs, fittings, and heavy underlying structure are often fastened to bonded structure and can have significant local thermal heat absorption differences during elevated temperature repair. These types of structure often are not a part of the original bonded assembly per the OEM production drawings, which can be helpful in determining if these types of structure should be removed before attempting an elevated temperature repair cure. See Figure 5 for an illustrated example.

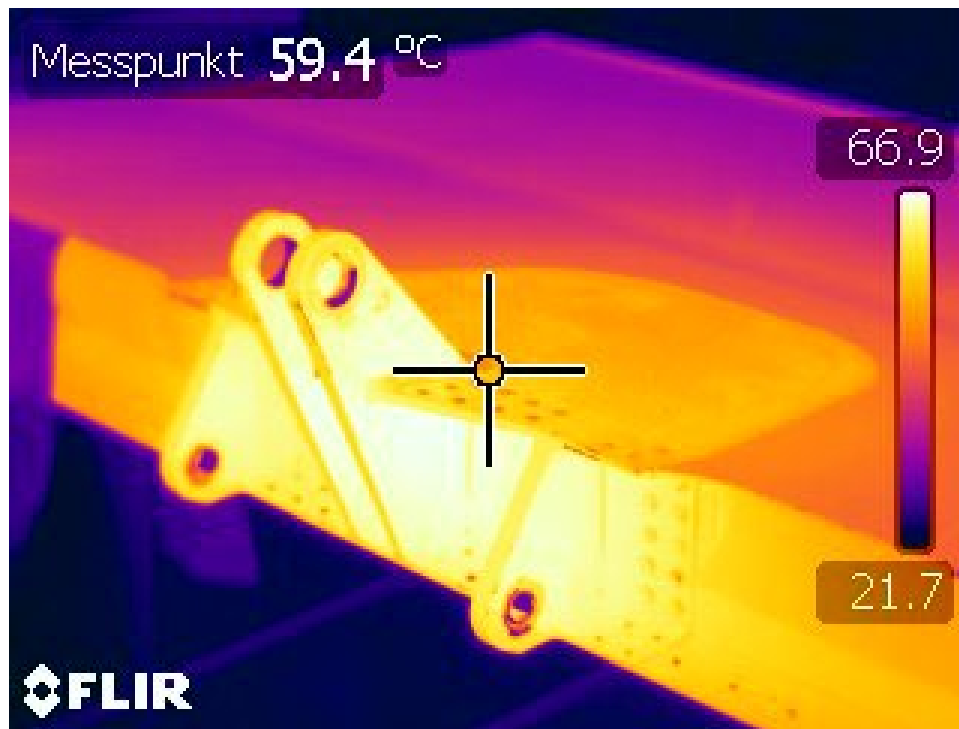


Figure 5 - Thermal image demonstrating how a metallic fitting acts as a heat sink
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Thermal imaging can determine areas difficult to heat beforehand. Figure 5 shows a thermal image of a spoiler that has been heated in an oven. After taken out of the oven, the fittings cool at a slower rate than thin composite structure. In the image, the temperature near the fitting is above 60 °C, while the structure farther away has cooled significantly. This is the reverse of what could happen during the cure cycle in a repair whereby heat is absorbed by the fitting and the cure temperature might not be reached.

- (3) Adjacent structure may not be rated at temperatures in the range of an elevated temperature repair cure cycle. Examples include fittings, sealants, or greases that may be damaged if exposed to temperatures beyond that allowed by a Customer supplied maintenance manual.

NOTE: As an example, it is common for some assemblies, such as flight controls, to have independent leading-edge structure that is attached to a bonded assembly. These leading-edge elements can have fittings containing seals, greased bearings, alloys that are not intended to see exposure to elevated temperatures, finishes, such as paints, primers, and other corrosion-inhibiting agents that could each be compromised if subjected to high heat. These types of items should be carefully considered before using an elevated repair cure. See Figure 6 for additional detail.



Figure 6 - Fitting bolted and sealed on the wedge after wedge manufacture

NOTE: Sealant can fail when heated above maximum permitted temperature.

A fitting (green primer) is bolted on the part (yellow tinted primer). It is likely that the sealant between the part at the fitting cannot withstand the elevated temperature needed to cure a repair. Degradation may not change the appearance or be detectable. Therefore, the fitting must be removed and reinstalled with new sealant after the repair.

- (4) It may not be possible to adequately apply a vacuum bag that provides the minimum required maintenance manual vacuum pressure and accepted leak rates for a vacuum assisted repair cure. The following provides examples where disassembly is required to install a vacuum bag to reduce risk of pressure loss during cure:
 - (a) It can be difficult to maintain vacuum for bonded panels that are attached to other structure if the damage is close enough to a joint that requires that the vacuum bag bridge across two separate assemblies.
 - (b) It is important to assess the likelihood that an adjacent structure could be subjected to crushing if further disassembly is not accomplished prior to a vacuum bag step.
 - (c) An assessment should be made on any potential bagging hazards, such as bridging, fastener heads, and sharp or irregularly shaped underlying structure/inserts, to make sure that the bag does not break during cure.
 - (d) If the original construction is comprised of two sandwich panels that are attached to each other, with air cavities between the two panels, do not bag both panels in one bag, i.e., envelope bagging, to prevent crushing of the two panels. The damaged panel needs to be removed from the assembly.
- (5) It may not be possible to conduct sanding and scarf operations required by the approved repair data for preparing the bond surfaces for structural repair. A repair technician can often be tasked with accomplishing sanding and scarf operations steps critical to the structural repair where space is limited or access is ergonomically difficult.

CAUTION: The strength of a repair cannot be assured when critical steps in the process are done poorly due to access, ergonomics, or insufficient lighting.

NOTE: Ergonomic handling during further operations may be improved with the structure removed from the aircraft. The repair can be performed quicker with good access to the damaged area during the sanding, scarf, cleaning, and layup operations required for the structural repair. Efficient tool access and risk of accidental damage to surrounding structure can be improved by removing fittings close to the damage.

- (6) It may not be possible to maintain maintenance manual required cleanliness, humidity, temperature, or other environmental requirements.

NOTE: Although a local CCA can be used when part removal is not possible, for most parts, removal and repair in an environmentally controlled area is more suitable than using a local CCA.

4.3.7 Disassemble the Part

- A. This section is applicable to both the removal of the damaged component from the next higher assembly and to the removal of fittings and parts from the damaged component.

B. Disassembly of Fastened (Non-Bonded) Structure Prior to Repair

- (1) If any structure removal instructions were identified in the previous section, review the Customer supplied maintenance manual removal instructions and make sure that all removal instructions can be accomplished without deviation, and that all required equipment and tooling is available for the repair.
- (2) If fittings must be removed, make sure that all tooling is available, if necessary, to realign critical hinge axis points, attach points, and any other critical functional aspects of the fitting upon reinstallation.
 - (a) It may be necessary to set alignment points using a specially designed AJ that captures a serial number specific set of key points. This set of points must be undisturbed until the repair is completed and fittings are reinstalled on the AJ that corresponds to that specific NHA serial number.
- (3) Parts may be installed with fay surface sealant which will make it difficult to remove without damaging the interface surface. Removal techniques such as using tools to pry, or the application of heat, could damage the interfacing plies; caution is advised when using these techniques. When prying/peeling fittings from the base assembly, tools should be used that will not gouge the base assembly, and materials should be selected that are not abrasive; use soft materials such as plastic or wooden scrapers. Cooling or heating the sealant, or the use of approved solvents, may also aid in breaking the faying surface seal. The success of these methods is dependent upon the type of sealant used. Refer to the applicable material specification or OEM document for appropriate sealant removal techniques.

CAUTION: Failure to use proper disassembly techniques on parts with fay surface sealant may cause damage to the base assembly, resulting in additional repairs or a scrapped part.

CAUTION: Sealant will retain its strength even when heated. If the heat is not controlled, damage may occur to the composite part, or the heat treatment of the metal parts may be affected. See 4.3.15.C.(2)(d) and 4.3.10.L.(3)(3), which discuss use of heat guns.

- (4) Composites are weak in out-of-plane loads. When separating parts, out-of-plane loads are needed. Even sealant is strong enough to cause fracture between the fiber layers. See Figure 7 for an example of damage.

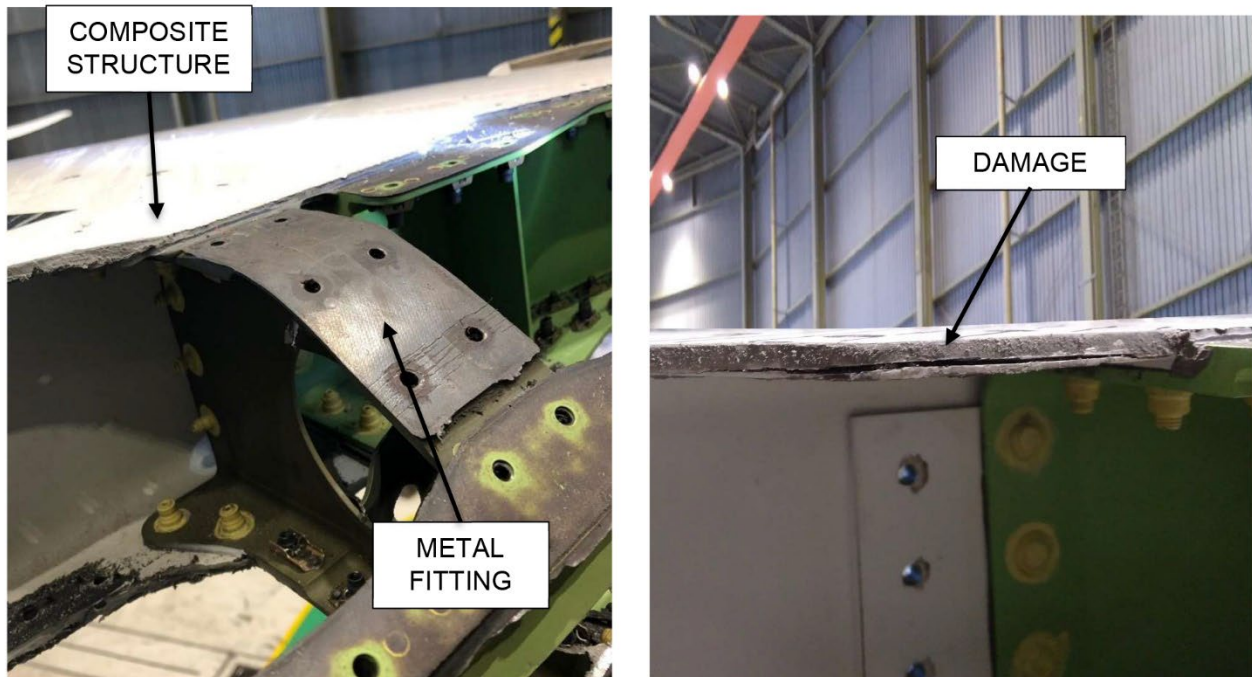


Figure 7 - Damage to surface plies after fitting removal

- (5) Composite parts can be easily damaged when drilling out fasteners due to mis-drills, heat from dull drill bits or spinning fasteners, and hole damage due to hole punch. See Figure 8 for an example of damage.

BEST PRACTICE: A fastener can be easily removed, after drilling out of a fastener head or removal of the fastener collar (if present), by twisting the fastener shank using pliers before gently pressing out of the fastener.

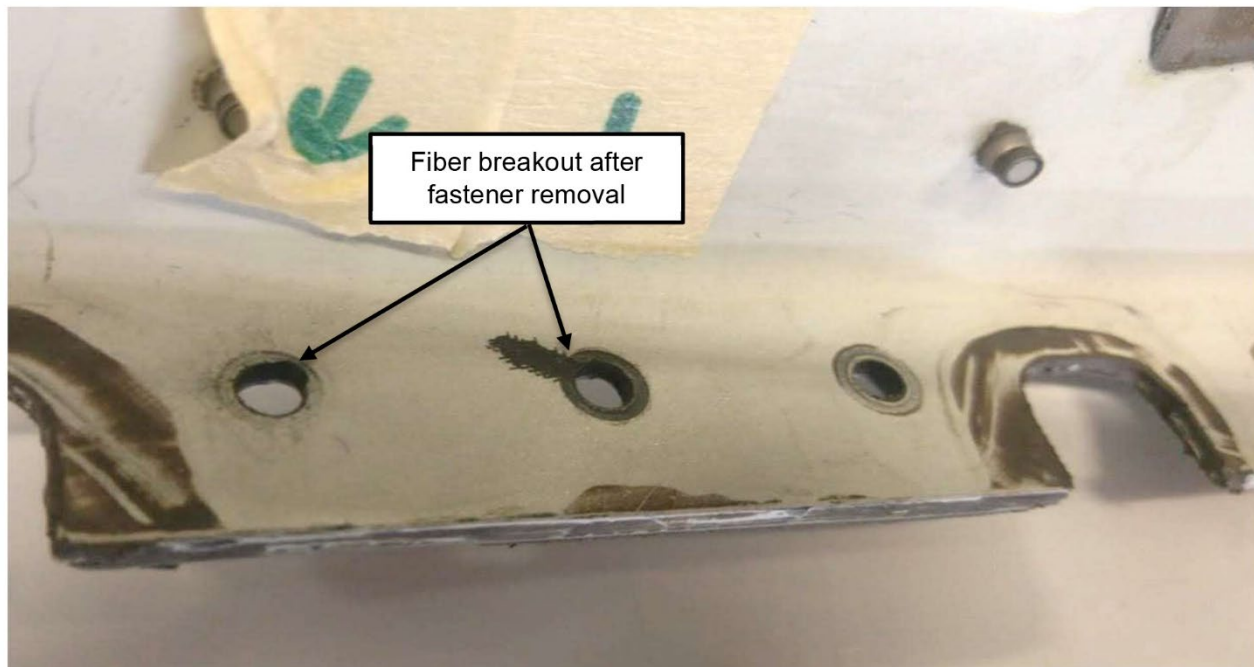


Figure 8 - Damage to holes after fastener removal

- (6) Fastener removal can cause damage in composite as the removal direction is a weak direction for the laminate. Removal with percussion tools should be avoided. Fiber breakout and delamination could occur.
- (7) A general visual inspection should be used to assess damage existence after part removal. If there are indications of damage in the surface plies or in holes where fasteners have been removed, an NDT inspection may be used to determine the extent of damage.

C. Disassembly of Adhesively Bonded Structure Prior to Repair

- (1) The use of cold or elevated temperatures is typically used to weaken the bond line. Removing an entire facesheet from a bonded assembly is typically not possible.
 - (a) It is best practice to apply cold temperatures using dry ice during the removal process, as authorized by the Repair Document. However, some research has shown that the use of extreme cold temperatures can strengthen the bond instead of weakening it.
 - (b) When applying heat during the removal process, as authorized by the Repair Document, caution should be used to ensure the part is not damaged, and the part temperature does not reach the original cure temperature, which could compromise the integrity of the part. See Figure 9 for an example of damage.



Figure 9 - Damage resulting from removing a bonded pressure seal on a pax door

- D. Perform all structural removals that were previously identified as being required. Use special care to not damage any underlying structure, as it is quite common to damage lugs, composite laminate plies, and honeycomb structure.
 - (1) Any parts that are to be salvaged and reinstalled after the repair is completed shall be tagged and identified with the part number, NHA part, and serial numbers. The parts shall be stored adjacent to the NHA that is being repaired so that parts are not lost or misplaced during the repair.

4.3.8 Make Sure Facilities Are Satisfactory

- A. Shop Environment - Review the Customer supplied maintenance manual and determine the appropriate facilities and equipment that will be required to accomplish the damage removal instructions.

- (1) The damage removal process creates dust and debris. Make sure that the damage removal is accomplished outside of any areas adjacent to controlled contamination/layup areas. Before proceeding, make sure to comply with all local regulatory environmental laws, taking particular note of chromates and asbestos.
- (2) Make sure that appropriate air filtering devices are available for use, including personal protection equipment (PPE) with proper filtration as well as designated grinding areas, if appropriate for the procedure being accomplished. It may be necessary to dedicate a special booth equipped with filtered air purge/exhaust capability.

CAUTION: The inability to control contaminants in adjacent repair areas may lead to a compromise in the repair strength of adjacent parts or assemblies being laid up/prepared for bonding. Airborne materials, such as carbon dust and silicone particulate, may contaminate bond surfaces and degrade bond strength which NDT is not able to detect.

- B. On Aircraft Environment - Review the Customer supplied maintenance manual and determine if a local protective area is required around the area of material removal. Local environmental laws may prohibit the uncontrolled generation and release of chemical particulates and may require equipment with dust recovery and filtration systems. It is recommended to work in a covered area protected from moisture at the material removal location.

4.3.9 Make Sure Personnel Are Qualified

- A. The technician responsible for assessing and removing the damage should have detailed knowledge of the structure so that, when removing the damage, the structure is not taken to a condition that is beyond economical repair.

NOTE: AIR4938, AIR5278, and AIR6825 give a summary of education levels and certifications for assessment and repair of composite structures. There are regulatory requirements for training.

4.3.10 Consider Non-Destructive Inspection (NDI) and Testing (NDT)

- A. Select NDI or NDT Method for Damage Assessment

- (1) Select an appropriate NDI or NDT technique to identify the extent of damage and to verify that the damage is completely removed. The Customer supplied maintenance manual will specify which inspection techniques are approved; however, the following considerations should also be made:
 - (a) The NDI or NDT technician should be trained or qualified on the equipment that is being used prior to evaluating the condition of any potential damage or defect and should have passed an evaluation on that equipment in accordance with the organization's repair station manual and should also possess any additional maintenance manual required certificates.
 - (b) If using audible NDI, such as sonic tap test, it is important that the technician be able to audibly detect a disbond in a joint from a standard that is made from the same gauge adherend/facesheet that is used on the actual part being repaired to account for individual differences in hearing acuity. The OEM NTM or NDT manual will typically give limits of detectable flaws and thickness limits for the test methods.

NOTE: Tap tests should be performed in an area that has low ambient noise in order to adequately evaluate the audible differences in pitch.

CAUTION: Tap testing is limited in its capability to detect damage. It is only appropriate for thin facesheet (~0.030 inch) sandwich construction.

- (c) X-ray or thermography can be used to determine if moisture has been removed in sandwich panels.

NOTE 1: Thermography is a reliable and cost-effective means of detecting trapped moisture.

NOTE 2: X-ray is a highly reliable means of detecting trapped moisture, as it is an expensive method and is typically used for high value components.

- (d) FTIR can be used to determine if the resin material has been heat damaged.

B. Select NDT Method for Repair Acceptance

- (1) Select an appropriate NDT technique to accept the repair. The Customer supplied maintenance manual will specify which inspection techniques are approved for the acceptance criteria for the repair process and structural configuration. The same considerations apply to repair acceptance NDT, as listed in 4.3.10.A.

BEST PRACTICE: NDT methods for inspection of repairs are Through Transmission Ultrasonic (TTU) if two-sided access is available and ultrasonic bond test methods, e.g., Pulse Echo (PE), if one-sided access is available.

NOTE: ARP5089 contains a summary of NDT techniques and capability.

C. Make Sure NDT Equipment Is Acceptable

- (1) Before using any NDT method, make sure that the equipment meets the calibration and certification requirements.
- (2) Make sure that, when required, reference standards which contain representative defects are available that match the construction of the part being inspected to make sure that readings of the equipment are calibrated properly.

D. Do the NDT Inspection

- (1) Do the NDT inspection as specified in the manufacturer's repair and NTM or NDT manuals. Remove any loose fibers and sharp edges beforehand which may interfere with the NDT method.

4.3.11 Remove Damage

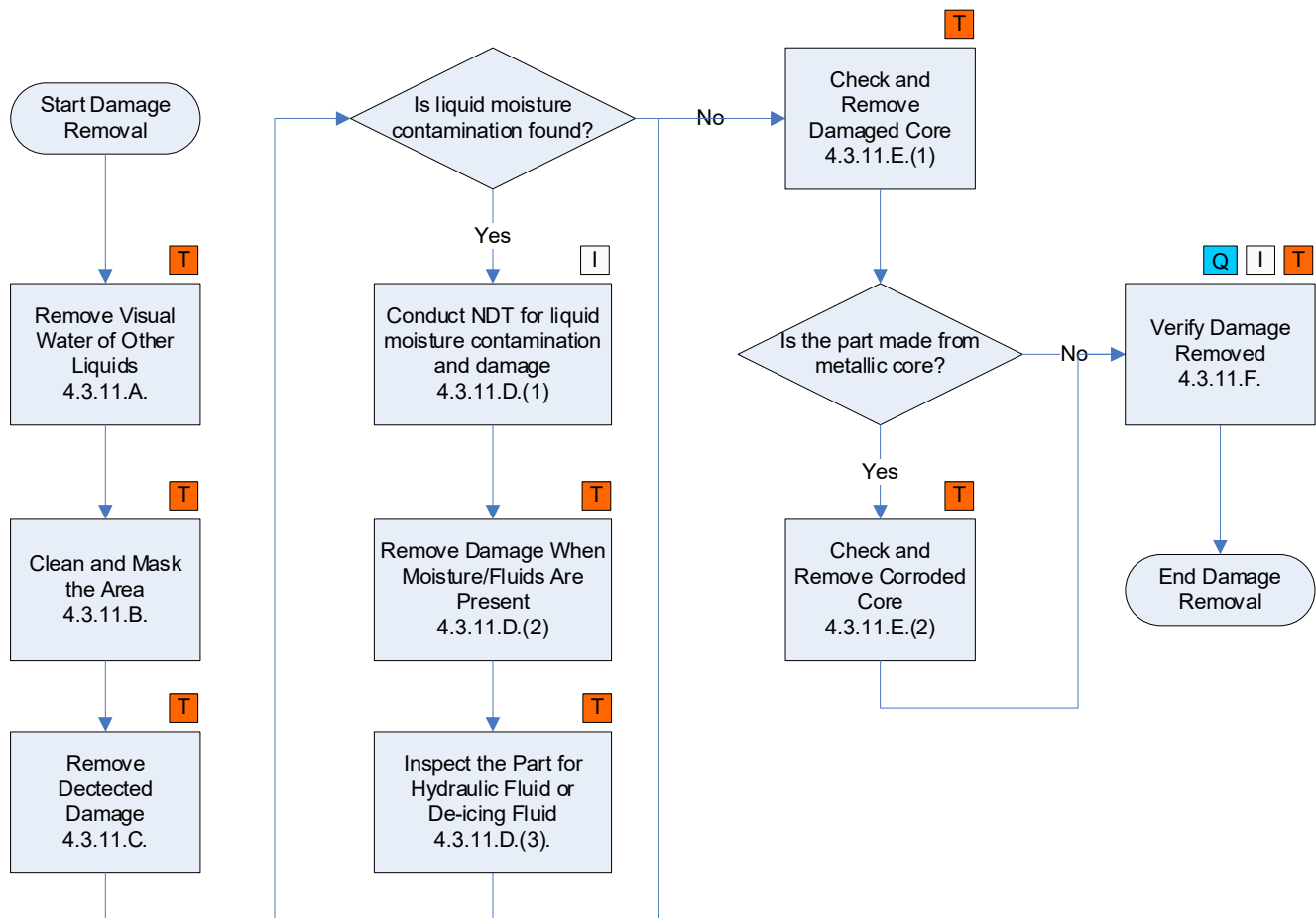


Figure 10 - Damage removal flowchart

A. Remove Visual Water or Other Liquids

- (1) Water or other liquid contamination is discussed in multiple locations in this document. Liquids/moisture can have either a physical or chemical detrimental effect on a repair. A physical effect occurs with increasing temperature and/or reduction in pressure during the repair, causing the liquid to boil and resulting in a pressure buildup. A chemical effect occurs when the moisture degrades the bonding strength and durability of the adhesive; an example is moisture absorbed into a composite laminate. This step in the process is specific to visible liquids. Visible water/fluids can be hidden inside the honeycomb cells, which is discussed in 4.4.7.A. Sections 4.4.7.B. through 4.4.7.J. consider absorbed moisture.
- (2) Liquid can collect on structures or inside through existing openings or damaged areas. It can generally be removed by mopping, vacuuming, or by blowing with compressed air (when it is water); refer to ARP4977 for procedures. Removal of liquid from honeycomb panels will usually require creating a drainage hole, or otherwise perforation, cutting, or removal of one skin to obtain access.
- (3) Contaminated areas that cannot be cleaned must be removed. Refer to ARP4916 for additional information.

B. Clean and Mask the Area

- (1) Clean and mask the area around the damage to prevent cross-contamination. Refer to ARP4916. Dirt and grime can be misinterpreted as damage when documented by photographs. Dirt and surface debris can prevent good contact for ultrasonic NDT inspection and interfere with other NDT techniques. Follow health and safety instructions.

C. Remove Detected Damage

- (1) In most cases, the minimum amount of damaged structure is removed to achieve a repair. Before removing damage, make sure that the repair size for the planned repair procedure permitted in the Repair Document corresponds with the maximum expected damage size. At this stage of damage removal, the full extent of the damage is often not known. Multiple removal/inspection iterations may be needed to fully remove the damage. For water damage, material may be removed until water is not visible, but this is insufficient to indicate no remaining damage. An NDT inspection after the damage removal step is recommended and often required to make sure all the damage was removed during machining process.

BEST PRACTICE: Provide the NDT damage report before damage removal to assist in developing the Repair Document. This information may provide an indication of the damage source and potential hidden damages. It also assists in minimizing the repair size or simplifying the repair should there be multiple defects.

- (2) Composite materials are abrasive and can cause higher drill and cutter wear than is experienced in machining of metals. AIR5367 contains more information on machining. The Repair Document may also contain references to machining parameters. The tool and the settings used in the repair must be appropriate for the type of structure to be machined, with aramid fibers in particular requiring special tooling. The quality of the cut degrades as the tool wears. The finish characteristics of each hole or cut should be continuously monitored during machining, and cutting tools should be changed before an unacceptable cut surface is produced.

CAUTION: Composite parts must be cut dry to prevent ingress of moisture/cutter fluids.

CAUTION: Composite structures must be supported, where possible, to reduce vibration during machining operations.

- (3) Check if there is a requirement for a template or splash tooling in the Repair Document. It is a best practice to make templates/tooling in the early stage of the damage removal step as some features required for the template or tooling could be removed during subsequent damage removal.
- (4) Commonly damage removal is often combined with step sanding or scarf sanding depending on the repair. This requires the removal of additional material from the component. If previous NDT was unable to determine the depth of the damage, the number of plies removed must be tracked during the damage removal stage. For example, for a lightning strike damage on carbon structure, the black soot often prevents count of the number of plies before some abrasive removal of the soot. Care must be used to remove only the intended material since composite layers can be very thin and distortions are inherent to the fabrication method. The depth of a ply boundary can change in the laminate. There could be features in the layup, such as ply drop offs, that are not on the component drawing.

WARNING: During machining operations, PPE, including eye protection, should be worn by all personnel in the immediate area to prevent eye irritation and breathing dust created during the machining process. Health and safety procedures must be followed at all times.

CAUTION: Carbon dust can become electrically conductive. All electrical equipment and connectors in the local area should be covered to prevent carbon dust from settling in those areas. Both carbon and fiberglass dust are highly abrasive. Care should be taken to keep dust from settling on mechanisms, actuators, or other moving parts.

- (5) Abrasive techniques generate heat, which could lead to local heat damage of the composite.

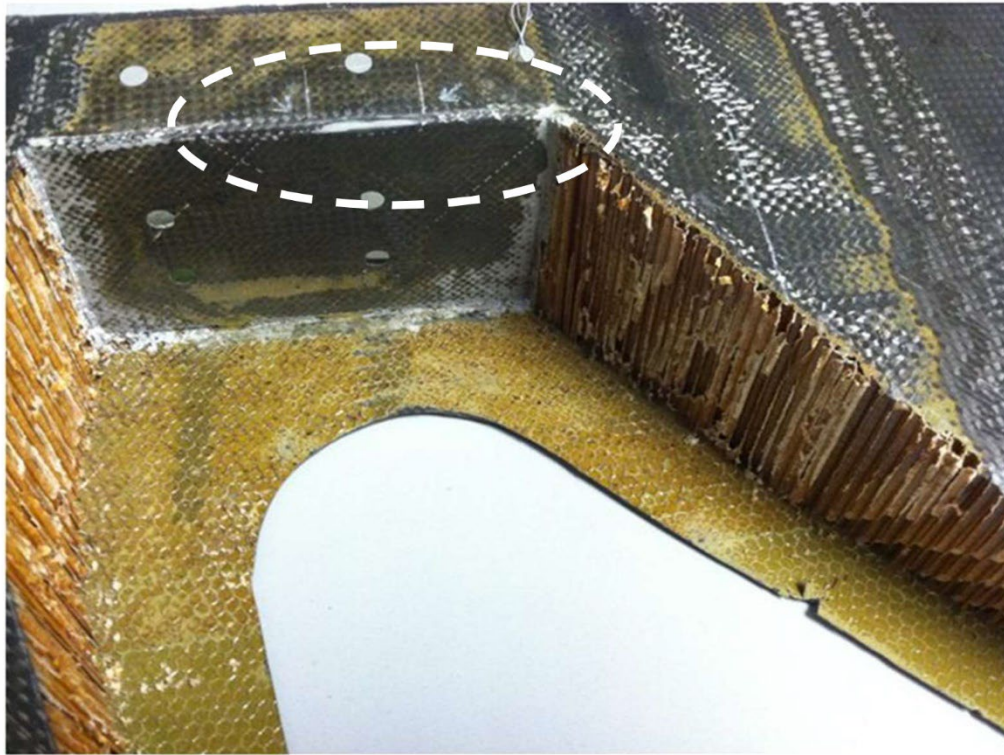


Figure 11 - Damage to carbon plies on the top radius due to excessive sanding

Care must be taken not to damage the fibers when sanding. Figure 11 shows a part where the honeycomb core had to be replaced. While sanding off the film adhesive residue, excessive sanding occurred on the top radius, and the fibers were damaged.

- (6) Rough cutting of the sides of the honeycomb can be achieved with a sharp knife. For final contouring, valve stem cutters and end mill are the preferred method, as referenced in AIR5367. For complete removal of the honeycomb core on one side when the facing on the material on the other side is thin, it is recommended to use hand sanding to remove the last remnants of the damaged core. It is also recommended to support the bottom.
- (7) The thin nature of the cell wall in honeycomb makes it prone to deformation. Nomex and para-aramid honeycomb materials will fray when machined with incorrect tools and setting.

D. Remove Damage When Moisture/Fluids Are Present

- (1) If there is a visual or other indication of water or fluid contaminants in sandwich components, conduct an NDT assessment of the extent of moisture contamination. See 4.3.10 for discussion of the various NDT methods available for determining whether there is moisture contamination. An example of moisture ingress detected by infrared thermography NDT is shown in Figure 12.

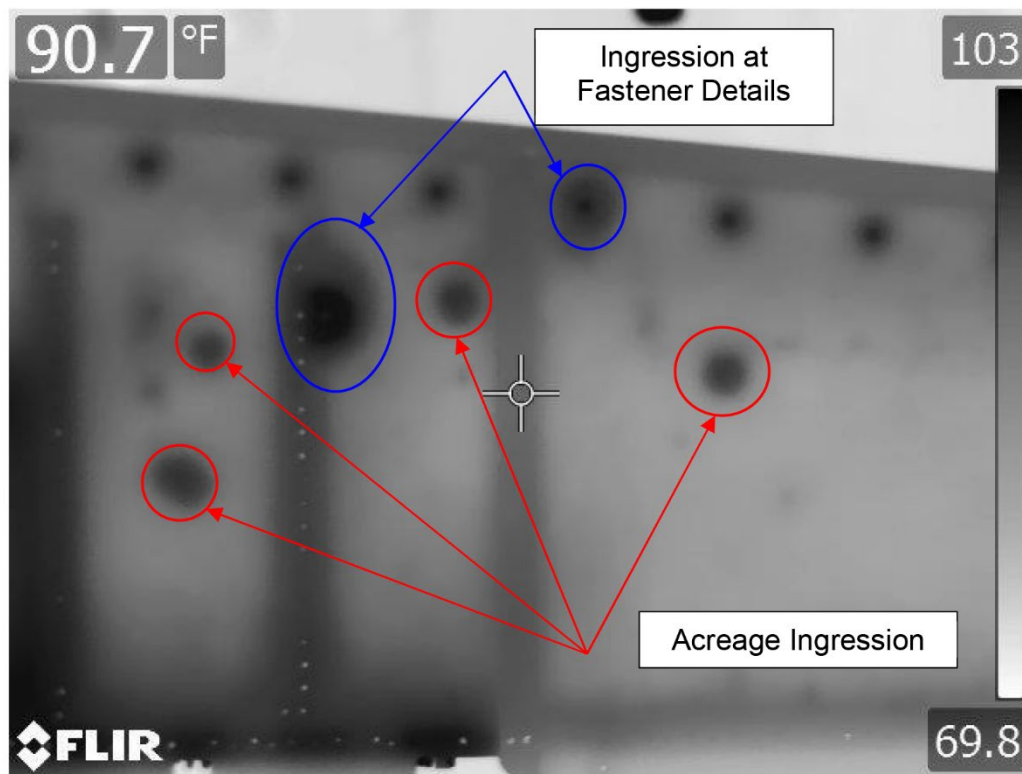


Figure 12 - Infrared thermography shows water ingress areas as dark spots on an elevator sandwich panel

Areas with moisture (or even standing water) act as a heat sink. This principle is used to detect moisture in this elevator skin panel where the dark spots represent a lower temperature and are therefore locations of moisture ingress in this part.

- (2) At locations where moisture or fluid contamination is found, open structure to access core. If the skin is removed, it should be for a sufficiently large area to cover the area to be heated during the repair. An area larger than the contamination should be removed so that residual moisture will not cause the repair to fail. In instances where moisture contamination is found, drilling holes in the skin can be an alternative to removing the skin. Refer to ARP4977 for drying procedures.

CAUTION: When heating a part to remove moisture, it is important to keep finishes, sealants, and metal parts within approved temperature limits. See 4.3.2.

BEST PRACTICE: It is often economically better to replace extensively contaminated core instead of conducting time-consuming drying cycles. In circumstances where moisture is found throughout the part, it may not be possible to remove all the moisture and obtain an acceptable repair. Complete core replacement is recommended in these circumstances.

BEST PRACTICE: If drying is not required by the Repair Document, the locations of the part on the airplane may assist in the decision on whether to conduct a drying cycle. Components located on the underside of the airplane are more likely to have moisture contamination.

BEST PRACTICE: Components exposed to high heat, typically engine components, may not need a drying cycle, as moisture cannot be absorbed due to the service environment. Engineering judgment, though, cannot supersede requirements for drying and moisture removal as directed by the Repair Document.

BEST PRACTICE: Acoustic panels may not need a drying cycle, as moisture may not be absorbed due to airflow within the inlet. Engineering judgment, though, cannot supersede requirements for drying and moisture removal as directed by the Repair Document.

- (3) Visually inspect the component for hydraulic fluid or de-icing fluid. For fluid contamination that is not moisture, whenever there is indication of contamination in the core, remove the facesheet to access the core. An example of hydraulic fluid contamination is shown in Figure 13.
- (a) ARP4977 also provides guidelines on removing liquids other than water. Solvents and cleaners could be used to remove contaminants if allowed by the Repair Documents. Depending on the composite material, some contaminants are no worse than water and can be removed with the same methods, while other contaminants, such as paint stripper, could require the removal of the complete contaminated section.
- (b) In the example shown in Figure 14, the core has been contaminated through a moisture path through the forward edge band exposed to erosion. The panel is a lower fuselage fairing constructed of fiberglass/epoxy co-cured to an aramid honeycomb core. Remove contaminated core, or if permitted by Repair Document, clean metallic core by using a solvent rinse. All surfaces suspected of being contaminated must be completely free of residual fluid for a structural bond.

CAUTION: It is frequently not possible to accomplish a successful repair when hydraulic fluid or de-icing fluid has been absorbed by the core. Contamination cannot be completely removed from the part to obtain a clean bond surface. A structural bond cannot be obtained with a contaminated surface.



Figure 13 - Example of sandwich panel contaminated by hydraulic fluid

The panel, shown in Figure 13, shows a contamination with hydraulic fluid over a wide area.

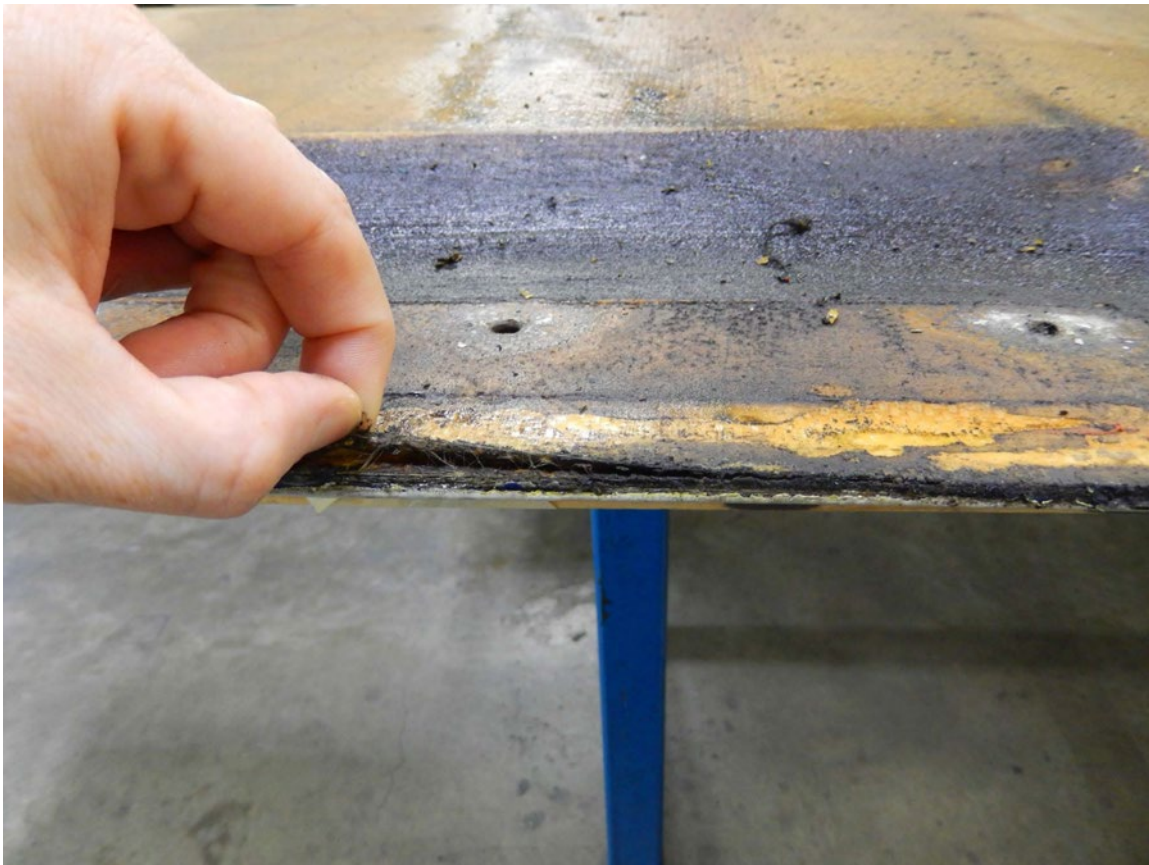


Figure 14 - Example of damage and moisture path for hydraulic fluid contamination

The leading-edge area, shown in Figure 14, displays a contaminated and delaminated edge band.

E. Inspect the core condition and remove damaged core.

- (1) Inspect the Part for Core Damage. A visual inspection for physical damage to the core should be accomplished. Types of core damage include:

- 1) Separation of the cell wall node bonds
- 2) Crushed cells
- 3) Fracture or torn cell walls

- (2) Inspect the Part for Core (Aluminum) Corrosion.

- (a) Visually inspect for local corrosion before finalizing the damage removal process. Aluminum honeycomb core often develops discoloration or white powdery substance (corrosion) on the foil. Non-corroded core should have a continuous silver color. See Figure 15 for an example of how corroded aluminum can extend beyond the physically disbonded area. Figure 16 is an example of corroded aluminum metallic core on a fan cowl after cutting away a secondarily bonded inner graphite/epoxy facesheet. Refer to AIR6291 for extensive discussion of core corrosion.

NOTE: Use of a direct light source (i.e., flashlight/torch) can help identify discolored core surfaces, which indicates corrosion.

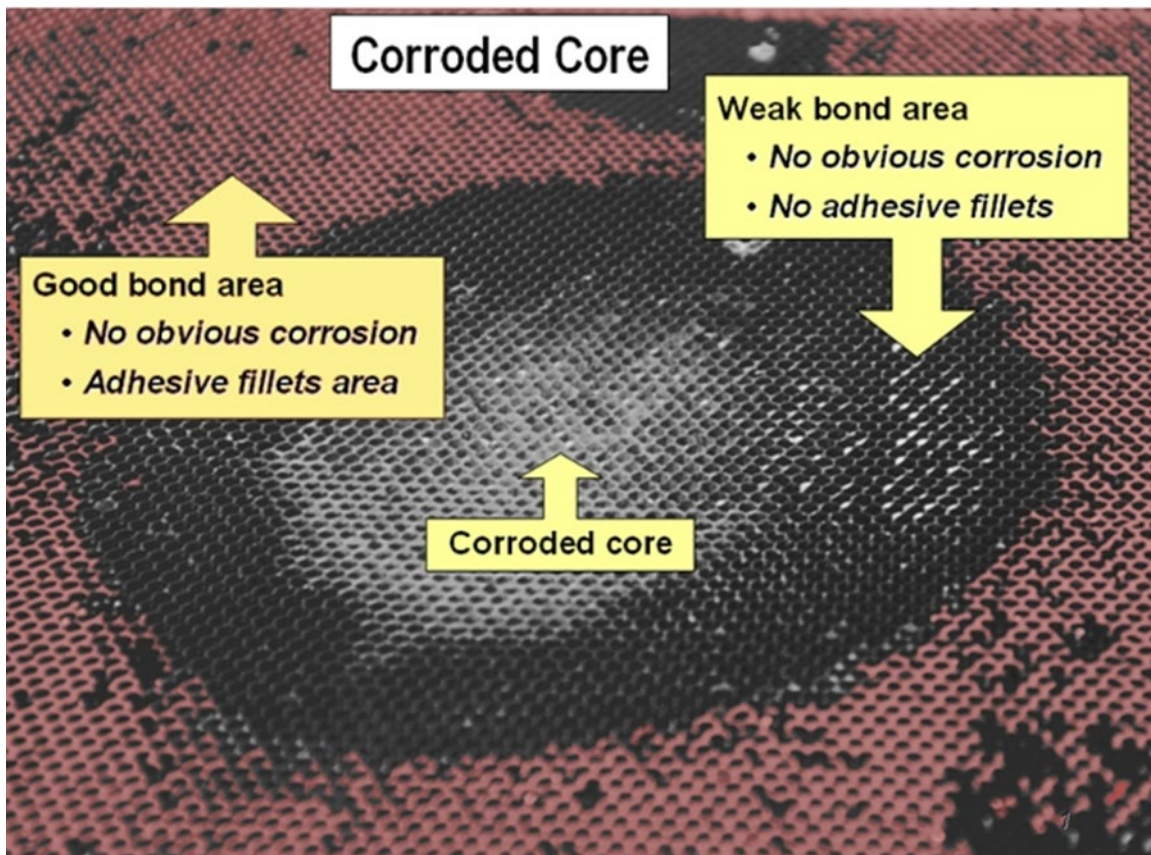


Figure 15 - Corrosion of aluminum honeycomb core resulting in a weak bond area

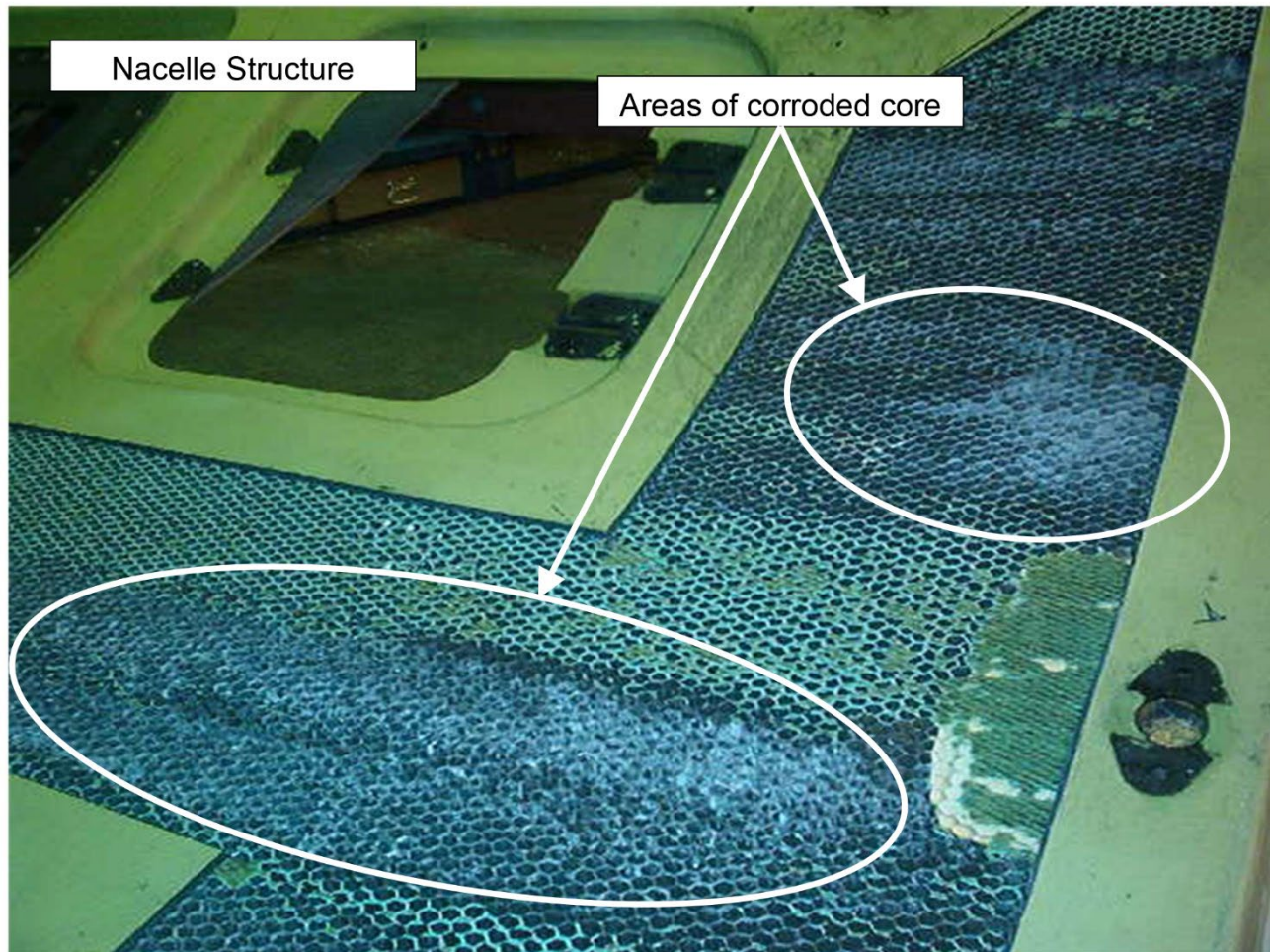


Figure 16 - Example of corroded core/weak bond/good bond areas

- (b) To find the limits of any weakly bonded skin, it is recommended that the skin be peeled back in a direction away from the area that has core already exposed from damage removal until strongly bonded skin is reached.

CAUTION: Weakly bonded skin is typically adjacent to disbanded areas. Such weakly bonded skin is not detectable by standard NDI or NDT methods, and if left in place, may result in actual disbond either during cure of a repair, or in a relatively short time following the repair when the part is placed back into service.

- (c) For non-corroded bonded areas, when peeling the skin from the core, the cell walls will typically break or tear, or the adhesive fillets will detach completely from the skin and will remain attached to the core. Another sign that corrosion has affected the core is the absence of broken core cells or adhesive fillets still on the skin.

(3) Remove Damaged and Corroded Core

- (a) Make sure that corroded core is removed.

CAUTION: Failure to remove corrosion is not acceptable because the strength and durability of the repair cannot be assured. One of the frequently observed causes of failure of repairs in service is due to incomplete removal of corroded core.

- (b) Verify that no evidence of corrosion exists at the edges of the facesheet cut-out. It is necessary to remove additional facesheet areas until there is no longer any visual evidence of corrosion in the core.

F. Verify Damage Removed

- (1) If additional damage is detected, repeat steps in 4.3.11 until damage is verified to be completely removed.

CAUTION: Moisture or other contaminants may migrate and may be present at locations away from the local area being repaired. Conduct a thorough evaluation and inspection of the part to make sure that all contamination has been removed. The durability and strength of the repair cannot be ensured if the contamination is not entirely removed in the part.

- (2) Remove debris and dust from the repair area and surroundings. Follow health and safety instructions.

4.3.12 Remove Protective Finishes

- A. Care is required for composites when protective finishes are mechanically removed as sanding procedures may damage the outer structural plies.
- B. Protective finishes are typically removed for control surfaces where hinge moments are controlled and radomes where control of paint thickness is required for functionality.

BEST PRACTICE: Do not sand through the primer layer.

- C. If a heat blanket repair is to be conducted, remove protective finishes in the area beneath the heat blanket.
- D. Sanding is the most common method for paint removal on composite components. Refer to AIR5367 for detailed procedure. Some components contain a layer of conductive material to provide protection against electromechanical hazard, such as lightning, which is a thin and fragile layer. A repair which reinstates electrical connection with this layer requires exposing, but not sanded through, this layer. Hand sanding is recommended to achieve this. See Figure 17 for examples of excessive sanding resulting in damage to fibers and conductive material.

CAUTION: Many paint materials are epoxy based and are similar in composition to the epoxy resins that make up the component surface or laminate. During paint removal operations, use extreme care to remove only the paint, and not damage the underlying laminate. In some instances, high performance finishing materials may be tougher to sand than the underlying surface of the component. Use extreme care to avoid exposing the fibers in the component surface. If the fibers are damaged, it may be necessary to expand the size of the repair as a result of fiber damage created during paint removal.

CAUTION: Chemical paint strippers can damage the resin matrix of the composite material. Exposure to chemical strippers that soften paints can cause similar damage to the epoxy resin in the composite component. Only OEM-approved chemical stripping materials and processes should be applied to composite components.

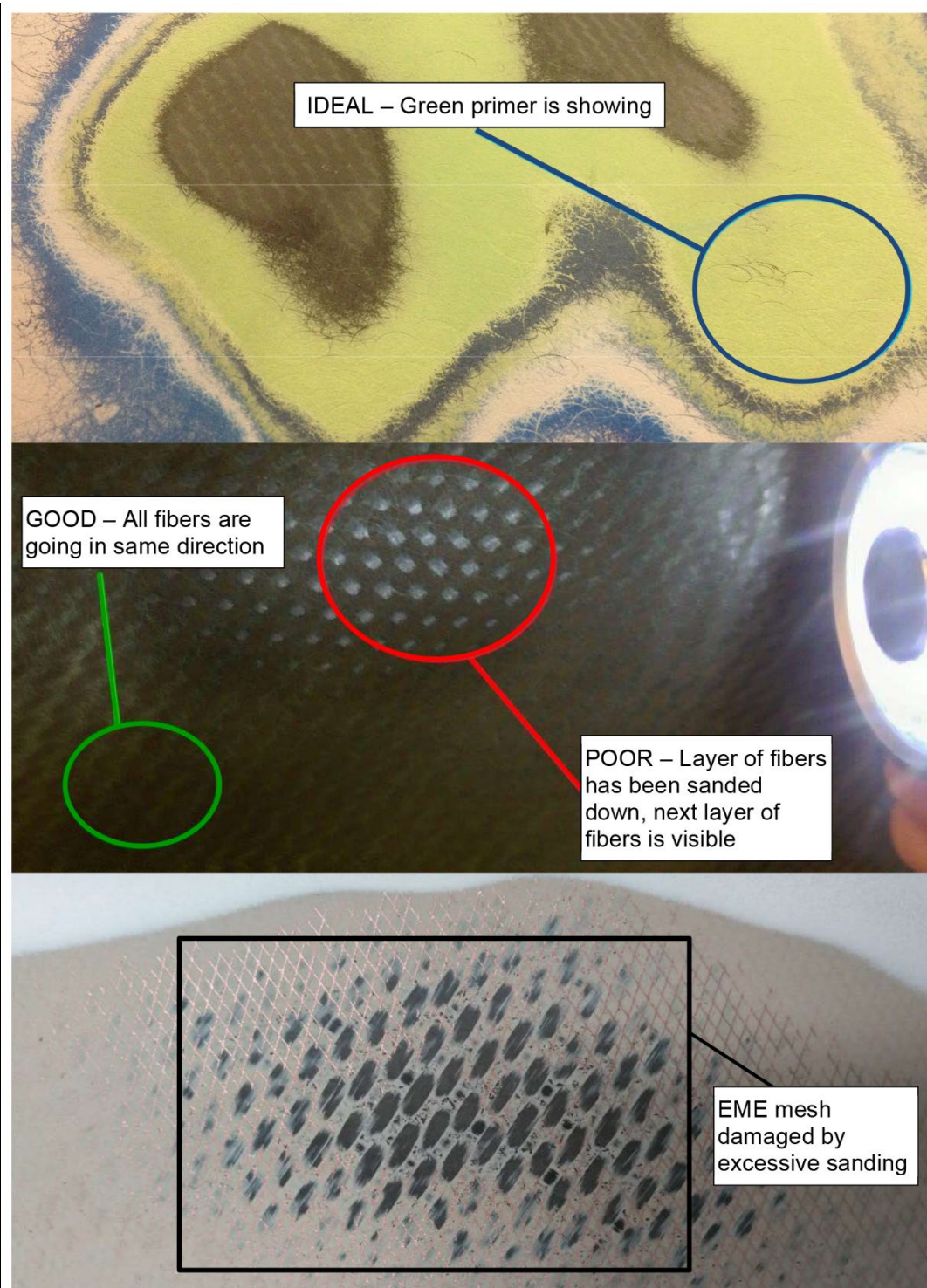


Figure 17 - Examples of damage due to over sanding

4.3.13 Select Applicable Repair Method

- A. Review the maintenance manual or SRM section that was determined in Step 4.3.1 for guidance on repairing the damage removed during Step 4.3.11. Make sure that the cleaned-up damage is within the limits given in the manual repair section before proceeding.
- (1) If the cleaned-up damage is determined to be outside of the limits established by the maintenance manual repair section as being repairable, contact the Customer engineering department to obtain an approved repair procedure in order to proceed.
- B. Determine if there are applicable Repair Documents using the applicable authorized source documentation. A realistic minimal estimate of the extent of the damage should be assumed at this stage. Damages in composite is often larger than visible from the outside, but smaller damage sizes often have more repair options.
- (1) If there are multiple repairs solutions in the authorized source documentation, determine which one would best suit the current need.
- (2) If currently no repairs could be found in the applicable authorized source documentation, contact the Customer, Engineering, or OEM. It is best practice to provide a damage report when contacting Engineering/OEM/Customer. Check whether the OEM gives guidance on the contents of a damage report in published documentation. The damage report should contain the following:
- (a) Identification of the damage part and aircraft when the part is installed on the airplane. This would consist of the part number, the serial number of the part when applicable, modification status, the aircraft serial number, the aircraft registration number, and the aircraft operator.
 - (b) Description of the type of damage (impact, disbond, delamination, gouge, etc.) and source of damage when known.
 - (c) Size of damage (length, width, depth). Different constituents can have different damage dimension. The depth information in composite can be either a dimension or the number of affected plies and layers.
 - (d) Location of the damage with respect to identifiable positions (fasteners/edges/fittings/changes in geometry).
 - (e) Location and description of previous/existing repairs to the structure as assessed in 4.3.3.D. when applicable.
- In addition, the damage report can contain the following:
- (f) Photographs of the damage in general overview with either the complete part or easily identifiable section of the aircraft. The photographs should provide information on the location and orientation on the airplane.
 - (g) Local photographs with a scale reference. These should show the damage, a ruler for scale reference and identifiable features on the part such as edges fittings and fasteners. If available, include the outline of the damage found in Non-Destructive Inspection (NDI).
 - (h) Detail photographs with scale reference to show the depth of the damage. Take into account that some composite materials may be hard to photograph in detail under adverse light conditions.
 - (i) Proposed repair approach based on published repairs. Include the preferred and/or available repair materials.
 - (j) References to similar damages could result in a faster response time from the engineering/OEM.

- C. The selected repair needs to be conducted using a Qualified Bonding System. Refer to AC 20-107B/AMC 20-29. The Repair Document provides instructions on how to implement a repair per a Qualified Bonding Process and must be strictly followed. The capability to conduct a repair to the specified Qualified Bonding Process must be confirmed. The Qualified Bonding Process must be demonstrated with repeatable and reliable processing steps and includes an understanding of the sensitivity of structural performance based upon expected variation permitted per the process. Even characterization outside the process limits is recommended to ensure process robustness. Refer to DOT/FAA/AR-03/53 for explanation of the critical effect of surface preparation to the adherends for initial strength, long-term durability, fracture toughness, and failure modes of bonded joints.
- D. The use of vacuum pressure can have adverse effects on some types of adhesive. Repairs that are accomplished without using proper pressure levels can significantly deteriorate the quality of the bond. Make sure that the proper vacuum techniques are selected for the adhesive. Some film adhesives are not suitable for use under vacuum cure and are susceptible to excessive foaming. Refer to AIR6291 for specific details.
- E. Specific to repairs using pre-cured details, other factors that can contribute to foaming of film adhesives include the following: not removing all moisture prior to bonding, improper orientation (scrim cloth up or down) of the film adhesive, improper cure or vacuum integrity, and omitting any required breathing assistance, such as positioning fabrics, which may or may not be required/allowed by the Repair Document.

4.3.14 Plan for Tooling/Quality Check

A. Tooling for Small Repairs

(1) Flat Plate

- (a) A flat plate may be suitable for use as a tool for repair of flat surfaces; however, you must verify that the part surface being repaired is actually flat or capable of being repaired on a flat surface.
- (b) Autoclave or oven tables may also be acceptable for use as a tool if verified flat. When choosing a table to be used as flat plate tooling, consider any possible heat sinks that could be problematic as well as the table's risk of warpage at elevated temperature.
- (c) A slip-sheet (between the tool and part) may be necessary in conjunction with the flat plate tool, to compensate for thermal expansion, if CTE differs significantly between the part and tool. Refer to AIR5431 for additional details.

CAUTION: Failure to verify the flat surface of the part by part, tool, or table could result in dimensionally incorrect repair parts. History exists where some parts were assumed flat but were not.

(2) Local Contour Support

- (a) A local contour support tool, commonly referred to as a caul plate or a splash, is often the best option for non-flat partial part repair. The subject tools are generally fabricated at the repair facility during the repair process for one-off repairs.
- (b) Caul plates (both rigid and flexible) are used in close contact with the layup, during cure, to transmit even pressure and maintain a smooth surface on the finished part. Caul plates are typically made from formed metal, flexible rubber sheet or similar elastomer polymers, or carbon/glass reinforced plastic molded to the desired part contour. Caul plates are generally less ridged than most other composite bond tools. If a caul plate is not used, surface irregularities may result from irregular pressure introduced by thermocouple wires and other irregular mating surfaces. If severe enough, these surface irregularities could reduce the strength of the repair.

- (c) Splash tools are tools which are typically developed by constructing a mold, by hand, from undamaged parts after covering with an adhesive-backed Teflon coated glass fabric or other suitable release agent. Splash tools are generally more rigid than caul plates depending on application. The splash process directly captures the desired contour of the area of repair from the undamaged part/master model, allowing it to be replicated in the repair. Splash tools have the advantage of not requiring digital data, programming, and milling which can delay tool development. When digital data is available or the resources are available to develop it, similar carbon/glass fiber reinforced plastics may be machined to the proper contour post cure. Local support tools made using digital contour data may be more accurate than splash derived tooling, especially if the digital data is obtained from the OEM of the part undergoing repair.

NOTE 1: When developing a splash tool, if a serviceable part is unavailable, it may be possible to use temporary filler to restore the shape of the damaged part for use in developing the tool; therefore, it is beneficial to develop a tooling plan before damage removal.

NOTE 2: Splash tooling is typically considered a single repair tooling concept because it costs less to remake the tool than the cost associated with identifying, storing, inspecting, and tracking its usage. Splash tooling can be used to perform multiple repairs provided it is inspected (leak check; detailed visual looking for cracks, surface imperfections, overall surface deterioration; etc.) and a fit check is performed to ensure the tool matches the contour of the component(s) the next repair(s) will be performed on.

- (d) Refer to AIR5431 for additional information related to general considerations, material selection, and advantages and disadvantages of different types of release film and release agents. A release layer must be used to provide release of the tool from the master model or the repaired component from the tool.
- (e) Local Contour Support tools are typically developed as single-use tools. If a tool is to be reused from a previous repair, it should be fit checked against a serviceable part to verify contour.

NOTE: Out of convenience, existing Full Contour support tools may alternately be used to accomplish local repairs in lieu of a local support tool. A Full Contour support tool may be needed for larger localized repairs or critical structure. Consult Engineering, if required, for evaluation of applicability of tooling.

B. Tooling for Major Repairs

- (1) If tooling is required by the repair procedure, for example, a Bond Assembly Jig (BAJ), an Assembly Mandrel (ASM), or an Assembly Jig (AJ), refer to the checklist in Figure 18 for the process of inspecting and preparing the repair tools.

NOTE: AIR5431 provides information on repair tooling.

CHECKLIST ITEM	REFERENCE PARAGRAPH	ACTION
Make sure that correct tools will be used to do the repair	4.3.14.B.(2)	
Make sure a thermal profile has been accomplished on all tools	4.3.14.B.(3)	
Make sure documentation is available for proper use of the tool	4.3.14.B.(4)	
Make sure all tools will maintain required geometries	4.3.14.B.(5)	
Make sure the tool has been stored correctly	4.3.14.B.(6)	
Make sure any required routine repetitive tooling checks have been satisfied	4.3.14.B.(7)	
Make sure release agent has been applied according to the Repair Document	4.3.14.B.(8)	
Make sure bond line verification has been performed on all tooling	4.3.14.B.(9)	

Figure 18 - Tooling check process checklist

- (2) Make sure that all tools that are specifically called out by tooling part number in the Repair Document are used for the repair.
 - (a) Verify that all tools being used during the repair were designed specifically for the part being repaired.
 - (b) Any deviations require prior written approval from the Customer.
- (3) For all BAJs and ASMs, verify that a thermal profile has been accomplished on the tool such that leading and lagging thermocouple locations are identified prior to completing a repair cure. Documentation of the thermal profile should be recorded and kept on file to aid the technician during thermocouple placement and autoclave orientation, as shown in Figure 19.

NOTE: Completing a thermal profile is a critical step to ensuring that repairs are fully cured.

- (a) AJs and ASMs can have large thermal mass (heat sinks) that can disrupt uniform heat up in a part being repaired. If thermocouples are not placed in areas that represent the leading and lagging heat up locations on the part and tool, it is possible for overheating/under-heating to occur. This can lead to under-heated or overheated adhesives, which can have detrimental effect on the material properties.
- (b) Positioning of the tool with respect to the convection heat flow direction is also critical and should be noted in the thermal profile report. Changes of the tool position with respect to the convection heat source may require a new thermal profile.
- (c) Using different ovens or autoclaves than were used to develop the thermal profile may also require a new thermal profile. For example, if a thermal profile was conducted at one supplier and a second supplier was selected to conduct a repair using the same process and tooling on the same part, it might be necessary to accomplish a new thermal profile.

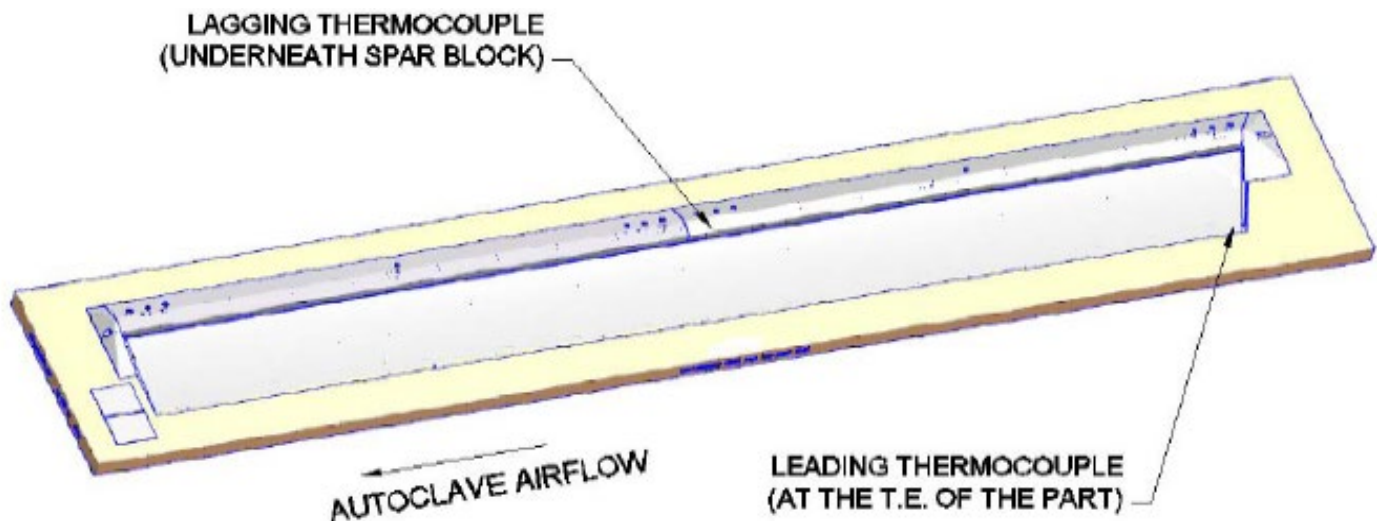


Figure 19 - Thermocouple diagram showing placement of thermocouples on tool

After the part and tool have been thermally mapped, the leading and lagging positions are determined and documented, including the orientation of the tool in the autoclave. Figure 19 is an example of a thermocouple diagram showing the thermocouple locations to be used on this tool.

- (4) Make sure that documentation is available regarding the proper use of the tool, such as a tooling drawing or a tool usage guide or manual. Make sure that all tools are properly labeled and identified to include ownership information.
 - (a) At a minimum, it should be evident, through these documents, how to properly rig the part that is being repaired on the tool being utilized.
- (5) Make sure that all tools have been shown to demonstrate, through validation checks, that the final repaired unit will maintain all required geometries, as specified in the Repair Document. See Appendix A for a detailed example of a preferred method of geometry verification.

NOTE: A record of where tooling geometry originates should be kept showing compliance with certification requirements. A repaired component must be validated to show that it meets form, fit, and function of the original engineering definition. High costs resulting from airplane downtime or for rework and scrapping may occur if a repaired component cannot be installed due to failure to meet contour.

- (6) Prior to use, make sure that the tool being utilized has been stored in accordance with all requirements for humidity, temperature, and any other requirements that are a part of the Repair Document, the tooling drawing, and/or the tool usage guide/manual.
- (7) Prior to use, make sure that any required routine repetitive tooling checks, such as general visual or dimensional inspections, that are required by the Repair Document Specification, the tooling drawing, and/or the tool usage guide/manual, have been satisfied.

NOTE: Using placards, as shown in the example in Figure 20, on the tool can help to make sure that the technician will have access to required inspection intervals.

**DELTA AIR LINES
COMPOSITE TOOLING PLACARD
(SEE DCS 2400 FOR USE)**

TOOL PART NUMBER	(1)	10M8625
TYPE / CATEGORY	(2)	O/M Cat II
MFG. DATE	(3)	08-10-00
CERT. DATE	(4)	09-20-00
DEPT. TRACKING #	(5)	382AT0001
COMPONENT USAGE	(6)	B767 INBD STRUT MID FAIRING
P/N EFFECTIVITY	(7)	313T1381-5,-6
	(7)	
	(7)	
TOOL SPEC. ER/A#	(8)	387677-14

TOOL OPERATING LIMITATIONS

PRESSURE	(9)	50 psi
TEMP	(10)	360 F
OTHER	(11)	

RELEASE AGENT	(12)	ZVYX WATERSHIELD
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REQUIRED DOCUMENTATION

CURE LOG (YES/NO) (13)	CONTOUR VERIFICATION (YES/NO) (14)	DRAWING (YES/NO) (15)
------------------------	------------------------------------	-----------------------

**COMPOSITE TOOLING CONTOUR
INSPECTION LOG**

TOOL PART NUMBER	(1)	10M8625
INSPECTION INTERVAL	(2)	6 MONTHS
SIGNATURE / DATE	(2)	J Doe (4) 3-23-01
SIGNATURE / DATE	(2)	(4)
SIGNATURE / DATE	(3)	(4)
SIGNATURE / DATE	(3)	(4)
SIGNATURE / DATE	(3)	(4)
SIGNATURE / DATE	(2)	(4)
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SIGNATURE / DATE	(2)	(4)
SIGNATURE / DATE	(2)	(4)

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Figure 20 - Example of tooling placard to keep track of inspection intervals and ensuring compliance to requirements

- (8) If a BAJ or an ASM is being used by the Repair Document, make sure that a release agent has been applied to the part-to-tool mating surfaces and that the specific release agent being applied is acceptable in accordance with the Repair Document.

CAUTION: Do not apply release agents near repair parts and parts to be repaired. Apply release agents outside of the controlled contamination area (CCA). Release agents that come in contact with a bonded surface will result a repair with insufficient strength.

CAUTION: Only use release agents approved by the Repair Document. Use of non-approved release agents have been a common source of bond surface contamination. Bond surface contamination will result in a repair with insufficient strength.

- (a) If an approved release agent has not been applied, clean the BAJ or ASM and apply an acceptable release agent to the part-to-tool mating surfaces per a process that is allowed by the Repair Document.
- (b) Release agents should be cured in accordance with the Repair Document and/or manufacturer's recommended processes.

CAUTION: Uncured release agents are a source of bond surface contamination. Bond surface contamination will result in a repair with insufficient strength.

- (9) Prior to use, it is best practice to verify that bond line verification has been accomplished to make sure that all repair details and tooling have been fabricated/designed correctly to allow for proper adhesive film thicknesses to be achieved during the cure process. If this has not already been accomplished, see Step 4.4.5 for further guidance.
- (a) Bond line thickness verification can identify areas of poor detail part fit up, resulting in low contact pressure and poor bonding.
 - (b) If a change in the supplier of any shaped/machined repair details has occurred, or if significant changes have been made to a repair detail drawing that might impact how two details interface during the cure, it may be necessary to conduct a new bond line verification procedure.
 - (c) Repair Step 4.4.5 gives additional detail on methods that can be used to accomplish a bond line verification check.

4.3.15 Plan for Thermal Management

A. Thermal Management Overview

- (1) Planning for thermal management is essential for a successful cure. A well-planned repair will be easier to maintain within the required temperature range during the cure and may also make the difference between a successfully cured repair versus a repair which needs to be scrapped and re-accomplished.

NOTE: Planning for thermal management accomplished per this section will be used later when executing the repair when thermocouples are placed in 4.4.11, the repair is bagged with insulation in 4.4.12, and the cure is monitored in 4.4.13.

- (2) Thermal management should be accomplished by taking the following steps:
- 1) Evaluate the difficulty for controlling temperature to obtain uniform heating of the repair using "Classification of Repair Types." See 4.3.15.B.
 - 2) Determine the type of heat source to be used using "Heat Source Selection." See 4.3.15.C.
 - 3) Develop a thermocouple placement diagram using "Thermocouple Placement Diagram Planning." See 4.3.15.E.
 - 4) Develop an insulation plan using "Insulation planning." See 4.3.15.F.
- (3) Since composite repairs are process dependent, it is critical that all areas of a repair remain within the required temperature range during the cure cycle. This will ensure that the cured resin or adhesive will develop the expected mechanical properties. The use of thermocouples is the only means to prove that the temperatures remain within required tolerances. The required number of thermocouples, as well as the requirements for thermocouple location, will vary depending on the size and complexity of the repair. In addition to monitoring the cure temperatures, thermocouple readings are also used by the heating device to control the heat blanket.
- (4) Any areas that are expected to be hotter or colder due to the thermal characteristics of the component should have a thermocouple to allow for proper cure control. This is particularly important in areas with a higher or lower thermal mass than other areas of the structure within the repair area. Areas with a high thermal mass (heat sinks) will typically result in a lower temperature reading during the cure and will respond to heating more slowly than other areas in the repair area. Areas with a low thermal mass will typically result in a higher temperature reading and quick response to heating. As the thermal complexity of the repair increases, the need for proper thermal planning before the cure, as well as active thermal management during the cure also increases. Thermal management during the cure may include addition or removal of insulation, addition of heat sinks, or addition of heat source.
- (5) Adjustments to the cure time length should also be considered. The curing phase, i.e., dwell or hold phase, is the stabilized temperature period for the minimum time to achieve the required cure. The planning for the repair, which may include results from a repair trial (thermal survey), may identify the need to extend the cure phase to ensure full cure.

- (6) Thermal surveys increase the amount of time the parent material is exposed to cure temperatures; therefore, the repair technician should follow any time-at-temperature limits contained in the Repair Document when conducting multiple repairs or thermal mapping. It is important to limit the temperature exposure as specified in the Repair Document to make sure that the strength of the composite repair can be proven.
- (7) The repair technician has responsibility for proper thermocouple placement in order to ensure the cure can be managed and uniform heating is applied throughout the repair. Repair Documents can be general in nature, and this places a higher burden on the technician for determining proper thermocouple placement. Alternatively, Repair Documents can be more specific with higher levels of detail for thermocouple placement. Regardless of the level of detail contained in the Repair Document, the technician must always be aware that factors may exist (repair environment, heat sinks, etc.) which were not fully accounted for in the Repair Document, and which might affect the actual number/and locations of thermocouples.

B. Classification of Repair Types

- (1) The first step of the thermal management process is to determine the thermal complexity of the repair, which will help determine what level of thermal management is required. The following repair definitions are intended to assist with thermal management planning.

(2) Simple Repair

- (a) A thermally simple repair has the following typical characteristics:

- 1) Single heat source.
- 2) Small number of plies which can be cured in a single cure.
- 3) Located in a “field area” of the part (no doubler ply drop-offs, no core ramps, no changes in core type or core density).
- 4) No heat sinks in or near the repair area.

NOTE 1: A repair in a solid laminate area of a part (e.g., edge band area) could be considered a simple repair if the heated area meets the basic requirements of the list above.

NOTE 2: A repair with multiple cure phases (e.g., core and skin plies cured in separate steps) might qualify as a simple repair if each step meets the basic requirements of the list above.

- (b) A simple repair typically requires a minimum of three thermocouples, spread evenly around the repair. Industry standard practice, though, commonly requires four thermocouples for redundancy.

(3) Complex Repair

- (a) A thermally complex repair varies from a simple repair if any of the following apply:

- 1) Multiple heat sources.
- 2) Large number of repair plies that require multiple repair cures.
- 3) Doubler ply drop-offs.
- 4) Core ramps.

- 5) Changes in core type or core density.
 - 6) Underlying or nearby heat sinks.
 - 7) Use of shop aid tooling or caul plates which result in a heat sink.
 - 8) Where heating blanket will overhang the edge of part.
- (b) A complex repair requires sufficient number of thermocouples to monitor areas within the repair that will heat up either slowly or quickly relative to other areas due to varying thermal mass or variability in heat source.

(4) Complex Repair - Repair Trials (Thermal Survey) Required

- (a) A complex repair may require a thermal survey. A thermal survey involves curing a surrogate patch (or trial patch) in place to evaluate the thermal characteristics of the repair area. A thermal survey is conducted to measure temperatures in areas of the repair that cannot be measured during the actual repair cure. Specifically, the temperatures at the bond line and within the stack-up of a thick repair are measured by embedding thermocouples in the bond line and/or in between the repair plies of the surrogate patch. The thermal survey serves to validate that proper temperatures are maintained during the cure cycle and that the thermal management plan is adequate. Refer to ARP5144 for guidance on conduct for thermal survey.
- (b) Thermocouple locations are to be determined prior to the thermal survey in areas where there is uncertainty in meeting the temperature profile required by the Repair Document. A thermal survey should not be used for only determining where the thermocouples should be located. Refer to ARP5144 for guidance on thermocouple placement.
- (c) Reasons for when a thermal survey is required may include any of the following:
- 1) Thermal profile is required for hard tooling used in autoclave or oven repairs. See 4.3.14.B.(3).
 - 2) When the OEM Repair Document requires a thermal survey.
 - 3) When there are details in the repair assembly that have substantially different thermal mass or conductivity, such as low-density core adjacent to high-density core, where it will need to be demonstrated that the part has achieved the proper cure profile and that standard thermocouple placement is not capable to provide the data. The concern is that one part will not achieve the desired temperature profile, resulting in either a localized under-temperature or over-temperature condition.
 - 4) Elevated temperature co-cured skin/core repairs which involve single-sided heating. The concern is the backside temperature may be lower as it is remote from heat source.
 - 5) Elevated temperature repairs which utilize multiple heat blankets. The concern is the splice between heater blankets where a gap may result in low temperatures, or an overlap of blankets may result in elevated temperatures.
 - 6) When there is a large number of repair plies and thick laminates under cure. The concern is achieving the cure profile of the bond line.

NOTE: Some materials may have exothermic reactions using a large number of repair plies.

- 7) When a heat blanket has difficulty conforming to a complex contour of the repaired component. The concern is either cool or hot spots where heat blanket is in contact or not with repair.
- 8) When the consequences of repair failure would pose significant risk to component structural integrity. The size of the repair should be taken into consideration. The location of the repair on the component, for example, areas of high stress level or adjacent to fittings, should also be taken into consideration.
- 9) When the complexity of the repair is substantially outside the experience of the repair shop.
- 10) When the technician is uncertain about the thermal characteristics of the part and/or a repair has not been done previously in the same area on similar parts.

NOTE 1: A trial repair may be conducted using a trial patch with release film or may be conducted on a scrapped component.

NOTE 2: A thermal survey needs to be conducted under the same ambient environment (e.g., stable temperature, still air) as the final repair. Refer to Pre-Repair Thermal Mapping section of ARP5144 for further detail.

(5) Hard Tool Repair

- (a) A Hard Tool Repair utilizes tooling that is similar or equivalent to manufacture tooling. Leading and lagging thermocouple locations are determined during development of the tool and recorded in the repair specification for future use. Section 4.3.14 contains discussion on processes for tooling for major repairs. Refer to ARP5144 for tool thermal profile procedures.

C. Selection of Heat Source

- (1) Different heating devices are available for repair curing. The Repair Document may restrict the damage size repaired by either heat blanket, or radiant heater, or hot air blower, when used in conjunction with low pressure vacuum bags, due to the type and structural classification of the component.

(2) Choose Heat Source

- (a) If the Repair Document specifies the use of a specific source, that heat source must be used. However, if the Repair Document does not require a specific heat source, use the following guidance for choosing the heat source. Refer to ARP5144 for more information.
- (b) Additional Guidance - Heat Blanket
 - (i) Heat blankets are the most widely accepted form of applying heat to a composite part to be repaired and are recommended by the OEMs for in-situ repairs. Heat blankets apply heat to the repair by thermal conduction. Heat blankets provide the capability of localized heating which can avoid globally heating the complete part, component, and/or assembly.
 - (ii) Heat blankets may not be a suitable heat source for complex part geometry. If a part has a compound curvature, bridging or wrinkling of the heat blanket could occur, which would result in local hot or cold spots in the repair. Custom contoured or stretchable heat blankets can alleviate this problem. If a custom contour heat blanket is not available, another heat source may be more suitable.
 - (iii) Regardless of repair size, it is best practice to use one heat blanket for the repair rather than multiple heat blankets, if the thermal characteristics of the repair can be adequately managed. When multiple blankets are used, the joint between the blankets increases the difficulty of conducting the repair as care must be taken to make sure that the blankets do not overlap which would cause a "hot spot" or leave a gap which would result in a "cold spot." Refer to Installation of Heat Blankets section in ARP5144 for more information.

