Composite Structural Engineering Course: Maintenance Interface (MI) Modules

Presented at:

2011 FAA/EASA/Industry Composite Transport Fatigue, Damage Tolerance, Maintenance & Crashworthiness Workshop

Prepared by: Peter Smith / Charlie Seaton

Presented by: Michael Borgman

Date: May 17, 2011

Objective of MI Modules:

- **Successful composite maintenance and repair (CM&R) practices rely on compliance with engineering assumptions made during design evolution**
- **These assumptions include (but are not limited to)**
  - Allowable damage limits
  - Repair size limits
  - Damage detection and removal approaches
  - Materials procurement, storage, and control standards (bonded)
  - Process constraints, control of “key characteristics”, appropriate tooling
  - Post repair NDI methods/considerations in validating final repair quality
  - Technician experience and training

Objective of MI Modules:

- **Develop skills needed within FAA workforce supporting composite applications**
- **Establish practical appreciation for the challenges of composite applications**

- ***Interface modules*** **aim to…**
  - Improve student understanding of these assumptions and their importance to final repair performance
  - Promote harmonization of design practices
  - Improve maintenance action oversight consistency

  ➔ Consistency and reliability in M&R related actions

MI Module: Student should appreciate damage types and M&R damage hazards

- **Damage sensitivity of composite components**
  - Monolithic
  - Sandwich
- **Damage hazards during CM&R activity**
  - Disassembly process
  - Component handling and storage (UV)
  - Damage removal
  - Contamination and moisture concerns
  - Cure processes
  - Tooling “breakout”
  - Re-assembly process

Maintenance Interface Modules

- **Section 3.5 Maintenance considerations**
  - related to composite structural development and service implementation

- **Section 7.0 Maintenance Interface Issues**
  - critical technical issues for composite maintenance and repair

Section 3.5

Section 3.5 Maintenance considerations

3.5.1 Importance of maintenance issues during design

Designing a maintainable structure

3.5.2 Importance of maintenance provision before service

Meeting engineering expectations assumed during repair design

Section 3.5: Topics Currently Included

- **Designing for maintainability and repair-ability**
  - What repair-ability target(s) are sought?
  - Should define M&R protocols during design evolution
  - Design for structural redundancy (progressive if possible)
    - Basic architecture & repair architecture
- **NDI method selection compatibility with fleet capability**
  - Training and equipment in place
- **Hybrid metal/composite structure considerations**
- **BVID and awareness of potential underlying damage state**
- **Fleet provisioning for equipment/education prior to EIS**
- **Mention existence of SRM (and relevant content)**
- **Mention existence of ADL's and RDL's**
- **Work area contamination and FOD control**
- **Pre-existing-repair proximity/interaction effects**
- **Consideration of thermal resilience and need for high T_g (wet)**

3.5.1 Importance of considering maintenance issues during design

- **Designing for maintainability and repair is essential during the development of composite aircraft structures**
  - Provision design for selected repair architectures
    - Laminate thicknesses conducive to bolted repair
    - Substrate compatible with selected bonded repair system(s)
- **Selecting a repair approach during the design phase will influence the choice of lay-up patterns and design strain levels.**
- **All composite components should be designed to ensure visual accessibility of the external surfaces.**

3.5.1 Importance of considering maintenance issues during design

- **During design of composite structural components consideration should be given to the inspection methods available to both the manufacturer and the customer.**
- **Most composite structural components will include metal fittings or interfaces with metal parts**
  - Desirable to ensure these metal parts can be visually inspected for corrosion and/or fatigue cracking.
- **Poor repair-ability can arise in service if maintenance is ignored during the design of composite structural components**

3.5.1 Importance of considering maintenance issues during design

- **Generally, during design of composite structural components, engineers ensure the components are capable of sustaining ultimate load with barely visible impact damage (BVID).**
- **This some times incorrectly promotes the service mantra "*if you can't see damage, the structure is capable of carrying the required loads*."**
- **In some cases, surface damage may NOT be representative of underlying structural damage and this mantra should NOT be generally applied**
  - Example 1: In monolithic structure, low velocity blunt impacts may promote surface BVID yet cause serious back surface and sub-structure damages.
  - Example 2: In sandwich structure, blunt impact can induce core debonding with little visible surface damage

3.5.2 Importance of provisioning for maintenance before entry into service

- **Maintenance information must be provided to operators at or before delivery of composite structural components**
- **The typical source documentation provided to operators and MROs is the structural repair manual (SRM).**
  - Information provide within the SRM will typically include
    - design configurations and details of each component
    - material types of each component
    - Inspection protocol for damage detection and evaluation
    - allowable damage limits (ADL) and zones
    - repair damage limits (RDL) description.
    - temporary and permanent repair descriptions
      - may also define zone locations with repair options
    - repair material options and process instructions for each option

3.5.2 Importance of provisioning for maintenance before entry into service

- **Training of customer maintenance personnel**
  - Technicians
  - Engineers
  - Inspectors
  - Management
- **Definition of environmental requirements for repair processing**
- **Definition of facilities and equipment requirements for proper maintenance actions**

Section 3.5: Topics Currently Included

What else should be included?

- **Designing for maintainability and repair-ability**
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- **Consideration of thermal resilience and need for high T_g (wet)**

Section 7.0

Section 7.0 Maintenance Interface Issues

7.1 Repair design and process substantiation

7.2 The need for teamwork and disposition

7.3 Composite damage types, characterization and detection

7.4 Bonded and bolted repair processes

7.5 Regulations that cover maintenance and repair

7.6 Source documentation

Section 7.0: Topics Currently Included

- **Airworthiness requirements for repair design**
  - Including EMI, HRF, Lightning, Protective coatings
- **Importance of integrated technical team**
  - Only as good as weakest link
  - Admit when you need help and where to get it
- **Types of defects/damages than can occur during manufacturing**
  - Porosity, void, debond, wrinkles, tool markoff and depressions, resin rich, resin poor, machining error, tool drop, handling damage
- **Types of damages that occur in-service**
  - Tool drop, runway debris, hail, bird strike, lightning, scratches, gouges, punctures, service vehicle impact
- **Categories of Damage (1 thru 5)**
- **Original design provisions for damages**
- **Barely visible versus Visible impact damage**
- **Awareness of back-side damage versus surface indication**
- **Considerations in *bonded* versus *bolted* repair**
- **Wet layup versus pre-preg**
- **Regulation and Guidance materials**
- **Source documentation**

Section 3.5: Topics Currently Included

- **Designing for maintainability and repair-ability**
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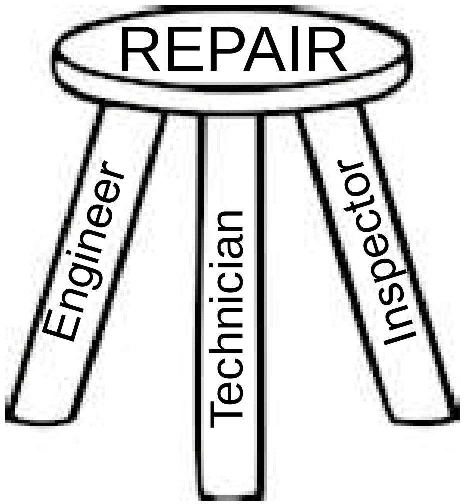
7.1 Repair design and process substantiation

- **Discuss the airworthiness requirements for repair designs**
  - Repair designs must meet the same airworthiness requirements as the base aircraft structure.
    - Strength and deformation
    - Durability and damage tolerance
    - Materials and fabrication methods
    - Material strength properties and design values (known and reproducible)
    - Weight balance, aerodynamic contour, flutter
  - All composite repair designs, materials and processes must be substantiated to meet airworthiness regulations. This should include substantiation for the effects of EMI, HRF, lightning strike and protective coatings

7.2 The need for teamwork and disposition

- **Reliable/repeatable repair is team action**
  - – Engineer must define robust repair materials and processes (that can be performed in fleet environment)
  - – Technician must have sufficient training and experience
    - Damage removal
    - Restoration
    - Key materials and processes characteristics
  - – Inspection must understand requirements
    - Damage detection protocol
    - Damage evaluation protocol
    - Quality assurance protocol



7.2 The need for teamwork and disposition

- **Discuss the importance of teamwork in composite maintenance**
  - Unique characteristics of composite materials, processes and design details requires team work
  - Team must possess knowledge and skill to satisfy procedural, regulatory and practitioner skills
  - Team success depends on skills and information of the participants: technicians, inspectors, engineers and OEMs

7.2 The need for teamwork and disposition

- **Teamwork essential for effective maintenance & repair**
  - Structural inspection/damage detection
  - Disposition of repair
  - Repair fabrication
- **Team members must recognize skill limits**
  - Be aware of skills of other team members
    - Awareness of all design and process steps
  - Know resources available when questions arise
    - Each skill set adds to the repair process

7.2 The need for teamwork and disposition

- **Disposition**
  - Damage detection
  - Visual discovery
  - Follow instructions of repair documentation
  - Damage assessment and mapping
  - Accurate damage mapping requires instrumented NDI procedure
  - Outside surface damage: Inspect inside surface if accessible
  - Extend inspection to adjacent areas to ensure no other non-visible damage or identify previous repairs

7.3 Composite damage types, characterization and detection

- **Types of defects and damages that can occur during the manufacturing process**
  - Fabrication processing can result in defects in composite parts, and carelessness during post-cure handling and assembly can also result in damages.
  - Defects may include:
    - voids, delaminations, porosity, wrinkles, tool mark-off, cure anomalies, poor bonds, “kissing” bonds, machining and drilling errors, impacts from tool drops or careless handling

7.3 Composite damage types, characterization and detection

- **Discuss the types of damages that may occur in service**
  - Repair processing or careless handling in the maintenance depot can result in the same kind of anomalies or damages that can occur during the original manufacturing process.
  - In-service damage sources include tool drops, runway debris, hail, lightning, airport equipment/vehicle impacts. In-service damage types include scratches, gouges, disbands to impact damages.

7.3 Composite damage types, characterization and detection

- **Explain what effect damage can have on composite structural components and how it may be different from the effect of damage to metal structural parts**
  - In general accidental damages affect composite structural parts differently than how metal structures are affected.
  - As an example a tool drop impact on a composite part may cause internal damage such as delaminations that are not detectable to the human eye, whereas the same impact to a metal part may well produce a dent which is usually easily detectable.

7.3 Composite damage types, characterization and detection

- **Categories of damage**

Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)

Category 2: Damage detected by scheduled or directed field inspection @ specified intervals

Category 3: Obvious damage detected within a few flights by operations focal

Category 4: Discrete source damage known by pilot to limit flight maneuvers

Category 5: Severe damage created by anomalous ground or flight events

7.3 Composite damage types, characterization and detection

- **In order to compensate for impact damages that may go undetected, OEMs such as Airbus and Boeing design primary composite structural components to be able to carry regulatory loads with what is termed barely visible impact damage (BVID).**
  - BVID is the smallest damage that may be detected by the naked eye from a specified distance (e.g. 5 feet) in good lighting conditions.
- **Damage that is considered easily visible is termed visible impact damage (VID) and may be serious enough to reduce structural capability below that required to carry regulatory loads.**

7.3 Composite damage types, characterization and detection

- **Viewing damage on one side of a composite may not reveal the full extent of damage.**
- **Of particular concern is the risk of non-visible damage resulting from low velocity high-energy blunt impacts (e.g. ground vehicle impacts), which may hide significant damages that are difficult to characterize.**
- **Due to the increased use of laminate stiffened composites in aircraft primary structures, visual and more rigorous NDI inspections of critical components may be directed by maintenance planning data (MPD) documents.**

7.4 Describe bonded and bolted repair processes

- **Bonded repair processes are typically preferred for thin laminates and/or sandwich components**
  - Provides effective load transfer - Capable of restoring the original strength of the damaged part
  - Current post-repair inspection is limited for bond line inspection
    - Quality control of the repair process is the basis of repair acceptance
  - Repairs must be performed per approved repair documentation
  - Prepreg bonded repairs
    - Original part prepreg materials
    - Approved substitute material
  - Wet layup bonded repairs
    - Two part epoxy resins
    - Dry fabrics
- **Bonded repairs generally size limited due to NDI limits**

7.4 Describe bonded and bolted repair processes

- **Typically bolted repairs are preferred for complex geometries or for primary structural components with thick laminates**
  - Less substrate material removal required (from undamaged structure)
  - Bolted repairs are generally simpler to process with less time and are more easily inspected for structural integrity
  - Bolted repairs do not require the same strict bond surface preparation and controls necessary for bonded repair
  - Fastener fit and hole tolerances must be tightly controlled to ensure load distribution meets design expectations

Regardless of the type of repair, whether bolted or bonded, any protective coatings such as for lightning strike and paints must be restored

7.5 Discuss the regulations that cover maintenance and repair (basic regulations)

European Aviation Safety Agency

The Regulation of Composite Aircraft Structures

EASA Certification Standards Design Linkage to Production and Maintenance

Design, Production, and CAW linked requirements (table from AMC 20-29 - rev. to CS 25.603 AMC Note 1)

	CS 23	CS 25	CS 27	CS 29
6. Material and Fabrication Development				
	603	603	603	603
	605	605	605	605
	609	609	609	609
	613	613	613	613
	619	619	619	619
7. Proof of Structure – Static				
	305	305	305	305
	307	307	307	307
8. Proof of Structure – Fatigue and Damage Tolerance	573	571	571	571
9. Proof of Structure – Flutter	629	629	629	629
10. Continued Airworthiness	1529	1529	1529	1529

Design link to production

Design link to CAW

Table continues with section 11 requirements – Crashworthiness, Fire/Flammbility, and Lightning

(Note: CS23 – small fixed wing, CS25 large fixed wing, CS27 small rotorcraft, CS29 large rotorcraft Certification Specifications (CS))

S.Waite - EASA, Cologne, Germany **Slide 12**

7.5 Discuss the regulations that cover maintenance and repair (basic regulations)

European Aviation Safety Agency

The Regulation of Composite Aircraft Structures
Basic Regulations

Basic Regulation EN 216/2008 regarding **airworthiness**:

Chapter 1 1 Article 5 1.d.3 '….manuals must cover …repair

6.f. 'All …repairs must comply with the essential requirements for airworthiness.'

Annex 1: 1.a.3. The manufacturing processes and materials used in the construction of the aircraft must result in known and reproducible structural properties. Any changes in material performance related to the operational environment must be accounted for."

Basic Regulation EN 2042/2003 regarding **continuing airworthiness**:

PART M, Maintenance Organisations Subpart B ***Responsibilities****:*

(g) Maintenance of large aircraft, aircraft used for commercial air transport and components shall be carried out by a Part-145 approved maintenance organisation.
(h) In the case of commercial air transport the operator is responsible for the continuing airworthiness of the aircraft it operates…

S.Waite - EASA, Cologne, Germany

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7.5 Discuss the ~~regulations~~ that cover maintenance and repair (advisory/supplemental)

- **Regulatory reports and guidance documents are available to aid in the maintenance of composite structures**
- **FAA and other regulatory agencies issue guidance for showing compliance of airworthiness requirements for composite structures**
  - AC 20-107A: "Composite Aircraft Structure" (EASA has AMC No.1 to CS 25.603. TCCA has AC 500-009)
  - AC 21-26: "Quality Control for the Manufacture of Composite Structures"
  - AC 23-20: "Acceptance Guidance on Material Procurement and Process Specifications for Polymer Matrix Composite Systems"

7.5 Discuss the ~~regulations~~ that cover maintenance and repair (advisory/supplemental)

- **Authorities publish guidance in the form of Advisory Circulars (AC), examples are:**
  - AC 43.13-1B, Acceptable Methods, Techniques & Practices – Aircraft Inspection & Repair
  - AC 65-2D, Airframe & Powerplant Mechanic Certification Guide
  - AC 91-56A, Continuing Structural Integrity Program for Large Transport Category Airplanes
  - AC 121-22A, Maintenance Review Board
  - AC 145-6, Repair Stations for Composite and Bonded Aircraft Structure

7.6 Discuss source documentation

- **The OEM is responsible for developing and providing a number of different source documents that contain maintenance, modification, rework, and repair information**
  - These source documents include maintenance planning data, aircraft maintenance manuals, component maintenance manuals, and structural repair manuals (SRM).
  - Service bulletins are also issued by OEMs, and serve as a means for sharing modifications to previous maintenance instructions.

7.6 Discuss source documentation

- **SRMs, or equivalent, are often the most complete maintenance document in terms of providing instructions for damage disposition, inspection, and repair.**
  - SRMs typically contain data that is approved by the appropriate regulatory agency. These include supplemental inspections, allowable damage sizes, and rework and repair instructions for specific composite components.

- **In absence of approved repair design: Alternatives include**
  - Contact OEM
  - Design and obtain approval for a specific repair for the damage
  - Replace damaged part

Section 7.0: Topics Currently Included

What else should be included?

- **Airworthiness requirements for repair design**
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- **Importance of integrated technical team**
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- **Types of defects/damages than can occur during manufacturing**
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