TCO E Module – Identify and Describe Information Contained in Documentation

E1: Describe Requirements in Material and Process Specifications and Approved Repair Information

Material and Process Specifications

To ensure that required standards are met, all materials and processes used in aircraft composite structural fabrication and repair must meet accepted specifications. For repair materials and processes, this means that sufficient research and testing has been done to establish repeatable material characteristics such as workability, shelf-life, out-time, bonding compatibility, and guaranteed strength and stiffness performance. This research and testing is then converted by OEMs or standards-developing organizations into material specifications that must be met by material suppliers, and process specifications or instructions that must be followed during fabrication or repair. Some standards-developing organizations include the Aerospace Standards branch of the Society of Automotive Engineers (SAE), American Society for Testing and Materials (ASTM), the International Organization for Standards (ISO) and others.

Each material specification specifies strength and stiffness requirements, material handling and workability characteristics, out-time requirements, and a set of acceptance tests and expected values. The acceptance tests are to be performed to ensure that the material received from the suppliers can be correctly processed in a component or repair to yield the specified strength and stiffness performance.

The SRM and component drawings call out materials and processes by the OEM company specifications or other specifications accepted by the OEM. Sometimes, the actual material supplier designations (e.g. EA 9390) may be used. Repair work must use materials and processes to these specifications or approved equivalents.

In Boeing SRMs repair materials are typically defined by their Boeing specifications (e.g. BMS 8-256), while the repair processes are laid out, step by step with diagrams and instructions. (Provide a sample Boeing SRM repair process page e.g. 777 SRM, 51-70-04, pages 235 and 237).

In order that structural repairs meet the specified strength and stiffness performance, the end-user must store, handle and process the repair materials per the process instructions.

Approved Repair Information

Structural repair manuals (SRMs) are often sources of approved OEM repair information. They are arranged per the indexing basis of the Air Transport Association of America ATA 100 system. This system allocates a number (e.g. Chapter 57 for wings) to all the major parts of the aircraft. SRMs only use Chapters 51 through 57 which are those ATA 100 chapters covering structures. Chapter 51 deals with general aircraft and repair topics, while specific repair information is provided in Chapters 52 through 57.

Examples of Boeing SRM chapters are:

Chapter 51: General information about the aircraft structure and repair information

Chapter 52: Doors - Passenger/crew entry doors
Cargo doors
Service doors
Fixed interior doors (flight compartment door)
Landing gear doors (nose, main and main gear shock strut doors)
Chapter 53: Fuselage
Chapter 54: Engine nacelles and pylons
Chapter 55: Vertical and horizontal stabilizers, elevators and rudder
Chapter 56: Windows – passenger, flight deck and door windows
Chapter 57: Wings – Wing center box
Outer wing main torque box
Wing tip/winglet
Leading edge and leading edge slats
Trailing edge and trailing edge devices – ailerons, flaps, flaperons and spoilers

Each section within the above Chapters 52-57 provide detailed information of a) the structural details of each component, b) allowable damage limits, c) repair options such as temporary, interim and permanent repairs and repair process instructions.

Structural details: The SRM presents diagrams of each component, associated drawing numbers, overall dimensions and lists of materials. Typically shown are sections cut through components or component panels, showing ply layups, orientations and core details if components are of sandwich construction. (Present page 8 of 53-60-70 of the 777 SRM showing a section through a fuselage fairing panel).

Allowable damage: Allowable damage covers minor damages that can be allowed without adding repair material, and with simple protection (e.g. Speedtape), the damaged component can be returned to service until it can be permanently repaired. Damages may be classified into several types such as dents, cracks, holes and punctures, delaminations, nicks scratches and gouges, with allowable damage sizes presented for each type. There are size and depth limits associated with each type of allowable damage, and limits of proximity to details such as edges, fasteners, other damages and previous repairs.

Repair options: There are often three repair options considered in approved data, temporary, interim and permanent.

Temporary repairs are allowed in order to permit aircraft to meet flight schedules. These repairs are typically time-limited, and must be removed before or at the time limit, and replaced with a permanent repair. The limits for temporary repairs are usually quite small due to lack of confidence in the durability of the materials used for these quick repairs. The cure temperatures for these repairs range from room temperature to 150^{o}F, thus they do not exhibit high strength and stiffness at high operating temperatures.

Interim repairs are those that can be allowed to continue in service indefinitely with scheduled inspections. These types of repairs are usually cured at 150^{o}F or higher

and consequently exhibit better durability and high temperature performance. The repair sizes for these repairs are usually larger than for the temporary repairs.

Permanent repairs are those repairs that are considered terminating actions and, in many cases, have no requirement for subsequent inspections outside those scheduled for the base structure. Bonded permanent repairs are usually cured at 200^{o}F or higher, and the associated size limits are larger due to confidence in durability and superior high temperature performance. In some cases, such as for more heavily loaded laminate stiffened components, a bolted permanent repair will be offered. Bolted repairs are offered for more highly loaded composite components such as B777 and A-320/330/340 horizontal and vertical stabilizer main torque boxes. These components are of a laminate stiffened configuration and employ many laminate plies in the skins, stiffeners and spars. Similar to permanent repairs offered for metal components, these repairs are often limited in size and location. In the case of critical to flight components, the SRM will present zones that range for less critical to most critical, and repair size limits will shrink accordingly. In the event of damage in some highly critical areas, the SRM will direct the operator or MRO to contract the OEM for a repair disposition.

Repair process instructions: Step by step instructions for temporary, interim and permanent bonded repair options are presented. Usually the temporary and interim repair options are wet layup methods. Typically for the permanent repair option, both prepreg and wet layup repair methods are offered, as well as bolted repairs for the thicker parts mentioned above. Exact step by step process instructions are presented (see TCO C2 for prepreg and bolted repair process instructions) for each type of repair. These steps usually include damage assessment and mapping, damage cleanup, surface preparation, material preparation, the actual repair process steps including in-process quality control instructions, post-repair inspection and finally surface restoration. An example of step-by-step bolted repair instructions is presented in TCO C2.

Typically allowable damage limits and repair instructions provided in an SRM are approved by the relevant regulatory authority and therefore are approved data. As an example, all Boeing SRM information is approved by DERs who reside at the company. In some cases, the data in some OEM SRMs (e.g. some general aviation OEMs) do not have adequate research and/or testing backup for it to be considered approved data. In the case of the use of the non-approved SRM repair schemes, each specific repair disposition must be approved by a DER.

Other Sources of Approved Repair Information

Many airlines have their own internal repair documents. These may include repair schemes for single large damages or repetitive damages of a minor nature. Approval for the singular large repairs will usually require the OEM's approval, while the repetitive minor repairs may have been approved by either the OEM or a local DER. In due time, repair dispositions for repetitive minor damages are usually added to the OEM's SRM. Repair for larger damages that are outside the scope of the SRM are sometimes not added to the SRM because they may involve several elements (e.g. a ground collision that damages a portions of a wing skin, a rib and a spar) and their interfaces (e.g. fastening).

Approved repairs for these types of large complex damages are typically stand alone, and are not considered sufficiently repetitive for adding complex instructions and diagrams to the SRM. In-house modifications may be made by operators to ease maintenance, or strengthen a part in increase durability or service life. In many cases modifications such as these may be adopted later by the OEM as a Service Bulletin, or if deemed necessary, adopted by the regulatory agency an AD (see E2).

E2: Demonstrate the Use of Source Documents

Service Bulletins are issued by OEMs and are the means by which modifications, inspections or rework instructions are automatically passed on to owners/operators and repairers (MROs) of OEM aircraft. There are several levels of priorities of Service Bulletins. These range from mandatory and alert which indicate that a high level of urgency is exists and flight safety is a concern, to a lower level of Service Bulletins generally called routine. Routine Service bulletins can deal with life or reliability extension recommendations for parts that have been troublesome in service, but for which safety has not been the issue.
Service bulletins may be issued as the result of an Airworthiness Directive (AD) issued by the FAA as a requirement to modify a specific component due to previously detected damage or partial failures. At other times an AD is issued to direct operators to perform a specific OEM service bulletin within a certain time frame.

Service Newsletters are issued by OEMs to address troublesome components or systems. The object of Service newsletters is to make operators aware of problems or potential problems, and solutions if any are available. Advice or methods of troubleshooting are often given in Service Newsletters.

Maintenance Planning Data (MPD) Documents are issued by OEMs to operators and MROs to provide specific inspection requirements and overhaul instructions for a specific aircraft. MPDs lay out preventive maintenance programs, which set fixed intervals for the overhaul and inspection of specific parts of the aircraft. They cover all parts of the aircraft, including structure, avionics, electrical and hydraulic systems, flight controls, power plants and landing gear. The MPD is consulted when an aircraft comes into the depot for a maintenance event such as a “C” or “D” check.
For structures, the MPD lays out the inspection intervals for specific components. As an example for composite parts, the MPD may require that the critical laminate areas adjacent to hinge fittings and actuators on rudders, elevators and ailerons be inspected at regular intervals, such as during “D” checks, using a specific NDI method to ensure that no delaminations have occurred). This type of MPD instruction would typically be the result of the area designated for inspection being considered critical to flight safety.

Structural Repair Manual
The structural repair manual issued and maintained by an OEM, is the source document that is consulted when damage to a structural component is discovered. Complete typical

damage/repair instructions are listed in C2, but the following generalized procedure is presented for using a Structural Repair Manual (SRM):

The damage is discovered on the ramp by ramp personnel or during a routine maintenance event by a mechanic or technician.
This damage must be assessed for type (delamination, hole, gouge, dent, crack, puncture or a combination of the fore mentioned damages), and mapped for size and depth. If the damage is discovered during a scheduled maintenance event, there will usually be a qualified inspector available to perform this damage assessment. If the damage is discovered on the ramp by ramp personnel, then the damage must be reported to a maintenance engineer who will ask specific questions to perform his own assessment.
In any event the specific section of the SRM that deals with the damaged component will be consulted for inspection requirements, allowable damage limits (ADLs) and repair instructions.
If the assessed damage is smaller than or equal to the allowable damage limit for the specific type of damage, then the part can be returned to service provided that the SRM instructions for damage removal or cleanup, contaminate and moisture removal, sealing and protective coating restoration are followed.
If the damage exceeds the ADL then repair instructions must be carried out. The damage must be cleaned up, and then repair options are considered. If the cleaned up damage is within the repair size limits for a particular repair option, then after contaminates and/or moisture have been removed, the repair can be carried out per the specified repair method. After the repair has been performed and inspected for acceptance, the part can be returned to service after restoration of protective coating or coatings.
If the cleaned up damage is larger than the repair size limits for all repair options, then the OEM must be consulted for a repair disposition, a repair design can be produced by a delegated authority (DER) or with the assistance of the OEM, or the damaged part can be removed and replaced.

E3: Identify and demonstrate the use of regulatory documents

All regulatory authorities issue their own documents specifying requirements or giving advice for the operation of civil aircraft. The following are two of the most important regulatory documents.
Federal Airworthiness Requirements (FARs) and the Joint Airworthiness Requirements (JARs): These are the United States and European airworthiness requirement documents respectively. Other governments have their own documents, but they are usually the same or based on the FARs and JARs. Repairs performed while a US registered aircraft is in service within the US are controlled by the FARs and Advisory Circulars (ACs) devoted to the maintenance of civil aircraft. European registered civil aircraft operated in Europe are controlled by the JARs. If US registered aircraft operate to or within Europe, they must meet the standards of both the FARs and JARs. Similarly European registered aircraft operating to or within the US must meet the requirements of both.

Other important regulatory documents are **Advisory Circulars (ACs) and Airworthiness Directives (ADs)**:

ACs are issued by the FAA or JAA when some issue must be attended to or if standards in some area need to be improved.
An important Advisory Circular for composite structure is:
AC No. 20-107A "Composite Aircraft Structure." This AC sets forth an acceptable, but not the only, means of showing compliance with the provisions of FAR Parts 23, 25, 27 and 29 regarding airworthiness type certification requirements for composite aircraft structures, involving fiber reinforced materials, e.g. carbon (graphite), boron, aramid (Kevlar), and glass reinforced plastics. Guidance information is also presented on associated quality control and repair aspects.

Another Advisory Circular of particular interest for repair of composite structure is:
AC 145-6 "Repair Stations for Composite and bonded Aircraft Structure." This AC is intended to provide information on the repair and fabrication of composite materials and adhesive-bonded components; and on the inspection systems, equipment, and facilities that a certificated repair station with the appropriate ratings should have to perform repairs or alterations on such materials and components. These guidelines are intended to supplement the procedures in OEM structural repair manuals. The AC provides good, broad information and guidance for operating a composites shop.

Another important Advisory Circular is **AC 21-26 "Quality Control for the Manufacture of Composite Structure."** This AC provides information and guidance concerning an acceptable means of demonstrating compliance with the requirements of FAR Part 21, Certification Procedures for Products and Parts, regarding quality control systems for the manufacture of composite structures involving fiber reinforced materials.

Advisory Circulars provide information and guidance concerning acceptable means, but not the only means, of demonstrating compliance with the requirements of the FARs.

ADs, also issued by the FAA, are instructions that must be complied with in the time scale set down within the specific AD. They are issued when urgent action is required to deal with safety issues concerning structural alterations, operating or maintenance procedures. In extreme cases, they could require grounding of an aircraft type pending investigation An example is AD 2002-07-08, issued in May, 2002 which directs the inspection of lap-splices on B737-200/300/400/500 aircraft at certain locations on the fuselage. This particular AD requires that the inspection set down in Boeing service bulletin SB 737-53A1177 be performed before the accumulation of 50,000 flight cycles of each aircraft. If cracking is discovered by the requisite NDI method, the AD directs the repair laid out in SB 737-53A1177 be performed. This AD was issued as the result of cracks found on a number of aging 737 aircraft and an in-flight incident.

Other regulatory documentation of interest in the US are FAR, Part 43 Maintenance, Preventive Maintenance, Rebuilding, and Alterations; and FAR, Part 145 Repair Stations.

FAR, Part 43 and the ACs associated with Part 43 specify methods which have been approved for repair and alteration. If a specific repair, designed and performed by an operator or repairer, is not already approved for use (i.e. described in the OEM's SRM), it must be transmitted in detail to the OEM for approval, or be given special approval by a DER.

Repair station certification requirements are given in FAR, Part 145. To obtain FAA certification, a repair station must submit documentation to demonstrate the skills of personnel, inspection procedures, and the necessary facilities and equipment.
Section 145.5 details certificate and operations specifications requirements. These are:

(a) No person may operate as a certificated repair station without, or in violation of, a repair station certificate, ratings, or operations specifications issued under this part.

(b) The certificate and operations specifications issued to a certificated repair station must be available on the premises for inspection by the public and the FAA.

Other section detail certification requirements such as:

(1) A repair station manual acceptable to the FAA as required by Sec. 145.207;

(2) A quality control manual acceptable to the FAA as required by Sec. 145.211(c);

(3) A list by type, make, or model, as appropriate, of each article for which the application is made;

(4) An organizational chart of the repair station and the names and titles of managing and supervisory personnel;

(5) A description of the housing and facilities, including the physical address, in accordance with Sec. 145.103;

(6) A list of the maintenance functions, for approval by the FAA, to be performed for the repair station under contract by another person in accordance with Sec. 145.217; and

(7) A training program for approval by the FAA in accordance with Sec. 145.163.

The equipment, personnel, technical data, and housing and facilities required for the certificate and rating, or for an additional rating must be in place for inspection at the time of certification or rating approval by the FAA. An applicant may meet the equipment requirement of this paragraph if the applicant has a contract acceptable to the FAA with another person to make the equipment available to the applicant at the time of certification and at any time that it is necessary when the relevant work is being performed by the repair station.

In addition to meeting the other applicable requirements for a repair station certificate and rating, an applicant for a repair station certificate and rating located outside the United States must meet the following requirements:

(1) The applicant must show that the repair station certificate and/or rating is necessary for maintaining or altering the following: (i) U.S.-registered aircraft and articles for use on U.S.-registered aircraft, or

(ii) Foreign-registered aircraft operated under the provisions of part 121 or part 135, and articles for use on these aircraft.

It is essential that composite repair stations have access to the FARs and/or JARs, ADs, and ACs, particularly those documents specific to composite aircraft structure. It is

essential that copies of these documents are available to maintenance engineers, and that they be fully cognizant of their contents. It is useful that inspectors and technicians are aware of these documents and that they have some knowledge of their general contents. Repair stations are well advised to provide access to these regulatory documents for technicians and inspectors.

E4: Understand the requirements and engineering approvals necessary for valid sources of technical information and maintenance instructions

In order for the safe use of composite materials in the manufacture and repair of aircraft structural parts, the FAA and JAA require compliance with the requirements of the FAR or JAR that covers the operation of each type of aircraft. As an example FAR Part 25 covers the operation of transport aircraft. Some of the important sections of this FAR that cover materials and processes are as follows:

Section 25.571 Damage tolerance and fatigue evaluation of structure.

(a) General. An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, or accidental damage, will be avoided throughout the operational life of the airplane. This evaluation must be conducted in accordance with the provisions of paragraphs (b) and (e) of this section, except as specified in paragraph (c) of this section, for each part of the structure which could contribute to a catastrophic failure (such as wing, empennage, control surfaces and their systems, the fuselage, engine mounting, landing gear, and their related primary attachments). Advisory Circular AC No. 25.571-1 contains guidance information relating to the requirements of this section.

(b) Damage-tolerance evaluation. The evaluation must include a determination of the probable locations and modes of damage due to fatigue, corrosion, or accidental damage. The determination must be by analysis supported by test evidence and (if available) service experience. Damage at multiple sites due to prior fatigue exposure must be included where the design is such that this type of damage can be expected to occur. The evaluation must incorporate repeated load and static analyses supported by test evidence. The extent of damage for residual strength evaluation at any time within the operational life must be consistent with the initial detectability and subsequent growth under repeated loads. The residual strength evaluation must show that the remaining structure is able to withstand loads (considered as static ultimate loads).

As stated in TCO C1, it is required that damage tolerance analyses be performed for any repairs made to principal structural elements.

Section 25.603, Materials, requires that:
The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must -

a) Be established on the basis of experience or tests.
b) Conform to approved specifications that ensure their having the strength and other properties assumed in the design data.
c) Take into account the effects of environmental conditions, such as temperature and humidity expected in service.

Section 25.605, Fabrication methods, requires:

a) The method of fabrication used must produce a consistently sound structure. If a fabrication process (such as gluing, spot welding or heat treating heating) requires close control to reach this objective, the process must be performed under an approved process specification.
b) Each new aircraft fabrication method must be substantiated by a test program

Section 25.613, Material strength properties and design values, requires:

a) Material strength properties must be based on enough tests of material meeting approved specifications to establish design values on a statistical basis.
b) Design values must be chosen to minimize the probability of structural failures due to material variability.

Section 5 of Advisory Circular 20-107A, Composite Aircraft Structure, sets out material and fabrication development recommendations. It states that "To provide an adequate design database, environmental effects on the design properties of the material system should be established.

a. Environmental design criteria should be developed that identify the most critical environmental exposures, including humidity and temperature, to which the material in the application under evaluation may be exposed……..Experimental evidence should be provided to demonstrate that the material design values or allowables are attained with a high degree of confidence in the appropriate critical environmental exposures to be expected in service.
b. The material system design values or allowables should be established on the laminate level by either test of the laminate or by test of the lamina in conjunction with a test validated analytical method.
c. For a specific structural configuration of an individual component (point design), design values may be established which include the effects of appropriate design features (holes, joints, etc.)."

Section 9.h Substantiation of Repair of AC 20-107A states "When repair procedures are provided in FAA approved documents or the maintenance manual, it should be demonstrated by analysis and/or test that methods and techniques of repair will restore the structure to an airworthy condition."

It can be seen that, while the requirements listed above were set down to cover the original structure materials, design values and fabrication methods; they apply equally for repair of these structural parts. Materials and processes used in repair of aircraft composite structural parts must be the result of qualification programs that provided the

detailed information and engineering practices to help ensure the control of repeatable material properties and processes. The qualification programs must generate statistically-based material properties for critical loading modes and environmental conditions.

Repair instructions laid down in a SRM are based on material and processing qualification testing that ensures repeatable material properties and processes. These instructions are approved by a delegated authority within the OEM (i.e. a DER). Structural repair materials are subject to material specifications that detail storage and handling instructions to ensure that, if processed per the SRM instructions, a repair will meet the specified design strength, stiffness and durability. Unlike typical metal materials, such as 20204-T3 or 7075-T6 aluminum alloy sheet or plate, composite material mechanical properties are dependent upon correct processing in the repair arena. Many metal repair materials can be obtained in the final condition, whereas composite materials are processed in the repair shop. It is therefore essential that materials are shipped, stored, handled, prepared and processed per source document instructions as for bonded repairs the actual repair processing provides the final material condition. Bolted repairs of composite parts are very similar to bolted repairs of metal components. Precured composite repair plates or metal repairs plates are utilized along with metal fasteners. Repair process instructions for bolted repairs are very similar to those of bolted repairs to metal components, with similar quality control and post-repair inspection requirements.