TCO H Module [including Laboratory #4] – Describe Composite Damage and Repair Inspection Procedures

H1: Describe NDI techniques currently available in the field

NDI techniques used in the field for composite part damage detection, damage characterization and post-repair inspection are typically less sophisticated than those employed by the OEM for their post-processing inspection. Some of the NDI techniques used in the field for the inspection of damage or defects in structural parts are:
Visual inspection, surveillance and detailed
Tap coin or hammer
Pulse echo ultrasonic equipment
Bond testers
Moisture meters
Eddy current equipment
Radiography

OEMs, operators and MROs all use visual inspection during post-manufacture and post – repair inspection for anomalies, but operators and MROs use visual inspection as their main technique for initial detection of damages, unless NDI techniques are specified by the maintenance planning manual. If visual inspections do not detect any damage during either surveillance (e.g. on the ramp between flights) or directed detailed visual inspections during planned maintenance events or after known events (e.g. tire or engine bursts, bird strikes etc.), follow up NDI inspections are rare.

While OEMs typically use water coupled Through Transmission Ultrasonic (TTU) methods for detecting anomalies in composite bonded parts; most operators and repairers use the tap test and the Pulse Echo NDI technique for mapping damages and for post-repair acceptance inspections.

Some operators and repairers use bond testers to inspect for delaminations and adhesive disbonds.

Moisture meters are often used by repairers and operators to detect the presence of moisture when making repairs to GFRP or aramid sandwich parts.

Most operators and repairers have eddy current equipment, generally used to detect cracks emanating from fastener holes in metal structure without removing the fasteners. This technique is of very limited use for detecting damages within composite structures and for inspecting repairs for integrity.

Similarly radiography (X-ray) is often used by aircraft MROs to inspect critical metal parts for minute cracks. For inspection of composite parts, x-ray of CFRP is difficult because the absorption characteristics of the fibers and resin are similar and the overall absorption is low. Detection of delaminations by x-ray is difficult because delaminations tend to be normal to the x-ray beam and thus make little difference to overall absorption.

The properties of glass and boron fibers are more suited to the use of x-ray as an inspection method for composites. X-ray is often used by OEMs as a complement to ultrasonic inspection because it provides indications of defects (e.g. cracks) in planes perpendicular to defects detected using ultrasonic methods.

All of these inspection techniques are described in detail in TCO C3.

The following NDI techniques are those most likely to be used in service to support inspection and mapping of damage, and for post-repair acceptance inspection:

Visual inspection: Visual inspection is used by operators and MROs for initial damage detection. For those composite structures designed to be able to carry regulatory loads with damage that is not visual to the naked eye, this is an appropriate technique for detecting damages that may be critical to flight safety. If damages to structural components are not visible and may be critical to flight safety, these areas should be designated as critical and NDI inspection specified in addition to visual inspection. Most, if not all, aircraft operators use visual inspection for surveillance of structural components on the ramp between flights.
During planned maintenance checks or directed inspection after known damage events, detailed visual inspections are performed. Maintenance Planning Manuals may edict ultrasonic inspection of specific areas of critical components (e.g. areas adjacent to elevator and rudder actuator and hinge fittings), but all directed inspections start with a visual inspection. After a repair has been performed, the repaired area is first visually inspected before using a tap test or ultrasonic techniques. The edges of the bonded repair are visually inspected for adhesive bleed out. For glass repair patches, visual inspection can often detect areas of disbonded plies within the glass patch. These anomalies can show through the laminate as discolored areas.

The following NDI techniques are used in damage characterization and mapping for damage disposition:

Tap Test: Most commercial and military aircraft operators use the tap test for damage detection in composite sandwich components. Tap testers range from a simple coin, to a tap hammer, to more complicated automated tap hammers. The tap coin and tap hammer are simple to use, and many seasoned inspectors can map damages very accurately in sandwich structure with thin face sheets. When inspecting sandwich parts with thin face sheets, a gentle tap on the surface of a good area will yield a clear sound of high frequency. A similar tap on the surface of a delaminated or disbonded area will yield a dull sound of lower frequency. As the number of plies increases, the accuracy of the tap method decreases. For mapping damages in the edgebands of sandwich parts and laminate stiffened parts, the tap tester tends to be ineffective. Tap testers are also used for detecting disbonds or damage in thin faced metalbond sandwich or metal doublers, but similar to composite parts, as the thicknesses of the aluminum face sheet and doubler go up (approximately above 0.04 in.), damage detection accuracy goes down.

Pulse Echo NDI: Pulse echo (P/E) is a portable ultrasonic technique that utilizes a liquid gel as the couplant and is particularly suitable for field work, i.e. damage characterization and mapping and post-repair inspections. Similar to TTU, pulse-echo inspection can detect small defects through the thickness of a laminate and disbonds between face sheets and honeycomb core. Compared with factory TTU inspection, P/E is quite a lot slower to use, and is not as useful for inspection of large components. It is more useful for inspecting areas that have already yielded visual damage indications. Most commercial aircraft operators will have pulse-echo equipment available at their maintenance bases. In order to obtain accurate readings and correctly interpret the results, the inspectors must be carefully trained in the use of the equipment. All ultrasonic NDI equipment must calibrated against known standard defects before use. Each time the equipment is used, the appropriate standards should be checked with the P/E equipment. At the OEM, a standard may be the smallest size of defect in a specific component that can be reliably found with the specific piece of equipment. More typically, in service, the P/E equipment is calibrated by use on a known good area of the structural component before being used for damage mapping or repair assessment. Some of the larger repairers or MROs store composite parts that contain known defects as standards for calibrating their NDI equipment before use in damage mapping.

Bond Testers: Bond testers are typically used to detect defects such as delaminations and adhesive disbonds. Bond testers are instruments that use the mechanical impedance method. They measure the change in local impedance produced by a defect when the structure is excited in the frequency range of 1 to 10 kHz. Bond testers are readily portable; thus, they are attractive for field service. They are well suited to the inspection of sandwich structures for face sheet separation from the core if small anomalies are considered not important. Gross defects such as wide-spread environmental degradation and face sheet disbonds in sandwich structure produce readily measurable changes in resonant frequencies. Large areas can be inspected for gross defects in a very short time.

Moisture Meters: Moisture meters are often used by operators and repairers to detect the presence of moisture when making repairs to GFRP or aramid materials. They can detect moisture within aramid honeycomb core. The usual type of moisture meters relies on radio frequency dielectric power loss. This power loss is attributed to an increase in the conductivity of the composite due to moisture absorption. Therefore, the techniques cannot be used with carbon or any other conductive material such metal, or with antistatic coatings that contain carbon.

H2: Describe critical steps necessary for making damage dispositions, including inspection and a draft process for QC plan for repair

Damage disposition:

Regardless of where damage is discovered; either during routine maintenance, on the ramp or as the result of a known event such as a tire or engine burst, bird impact or ground vehicle collision; the damage must be assessed and the extent of the damage mapped. When damages are detected during routine inspections in the maintenance depot, the instructions within the MPD and SRM must be strictly followed, and component and material records must be maintained. When damage is found on the ramp during normal operations, the MDP and SRM may not be available, but the damage must be reported to a maintenance engineer for him or her to make a disposition. Also the normal work documents may not be available on the ramp, but records of damages, inspection results, repair dispositions and materials used must be kept for entry into the component and materials records. Because approved repair documentation is unlikely to be available on the ramp, it is essential that operations personnel have access to qualified maintenance engineers in order that proper damage or repair dispositions can be made.

In order to accurately map any damage discovered visually, an instrumented NDI procedure should be used. A tap test method may be used if it can be shown that a defect or damage that is less than or equal to the maximum allowable damage size can be found. If damage is found on the outside surface, the inside surface should be inspected if accessible.

After any damage has been discovered and mapped, the first step in any damage/repair disposition is to consult the source documentation (such as the SRM) for allowable damage limits (ADLs) and repair designs. If the damage is less than or equal to the ADL for the specific component, then the source documentation procedure for sealing the damage and restoring the component to operation should be followed. As an example, for ADLs within Boeing SRMs, the instructions will typically include moisture removal, the use of aluminum speed tape and sealant, and restoration of the paint system and any other protection system. Most allowable damages that are sealed with speed tape are required to be inspected at regular intervals to check on the condition of the seal. Typical detailed Boeing B777 SRM instructions for allowable damages sealed with aluminum speed tape include:

a) Check the condition of the sealing tape at a maximum of 400 flight cycles, if deterioration is found, replace the sealing tape
b) Make a permanent repair after a maximum of 4000 flight cycles or two years, make a permanent seal and restore protective system (primer, enamel and any conductive coating)

If the damage is larger than the ADL and there is an approved repair available, the approved procedures set down for damage clean-up, moisture removal, surface preparation, repair processing and inspection must be followed precisely.

If the damage disposition is to perform a bonded repair, a quality control (QC) plan should be followed to ensure that the repair is processed correctly.

Quality control (QC) plan for a bonded repair:

In order to verify that all of the repair process steps have been performed correctly, a quality control plan is required in order that the technician or inspector can ensure that the approved repair instructions were followed. The approved repair documentation (e.g. SRM) step by step instructions are often used for quality checks, or the technician provides his own check list which another technician or an inspector checks off. A second person must be used to perform inspection activities, and is responsible for verifying the correctness of the process step, and for signifying on the work instructions that he has verified the process step.

The following steps must be verified prior to the actual repair cure cycle:

1) The protective coating (e.g. conductive coating if present, paint enamel and primer) must be removed per the approved instructions
2) The part may contain moisture and must be dried per the specific drying instructions
3) The damage must be removed and the repair scarf or steps must be cut accurately
4) The repair materials (i.e. prepreg or wet layup resin, film and paste adhesives and/or dry performs) must be collected and prepared per the approved instructions. The prepreg or dry performs and adhesive film must be cut to the correct orientations and size to fit the repair steps or scarf.
5) The adhesive ply and the prepreg or dry performs must be laid down in the correct order and orientation. In the event of a wet layup repair the dry perform plies must each be wetted-out appropriately per the instructions
6) If a debulk cycle is called for, it must be peformed using the required breather cloth, vacuum and heat for the prescribed period of time
7) After all of the repair plies have been laid down, the repair must prepared for cure. The correct bleeder, breather cloths, thermocouples, heat blanket, vacuum port and vacuum bag must be installed and sealed per the approved instructions.

If any of the above repair process steps is not carried out correctly or missed, a defective repair may result. In the event that a repair ply is missed out or laid down with the wrong orientation, an under strength repair may result.

In-process quality controls for a wet layup or prepreg vacuum bag repair are as follows:

a) After the vacuum bag has been installed over the repair and sealed, apply a minimum vacuum of 22 inches of mercury, keeping a minimum of 22 inches of vacuum throughout the cure cycle
b) Check the vacuum for leaks: After 22 inches of mercury has been attained, remove the vacuum source. Monitor the vacuum pressure, and after 5 minutes, the vacuum must be within 5 inches of the requisite 22 inches of mercury. If the required level of vacuum is not maintained, remove the vacuum bag seal, reinstall it and repeat the vacuum process.
c) Increase the temperature of the heat blanket by 1^{o}F to 3^{o}F per minute until the required cure temperature has been reached. It is usual to monitor the leading T/P for the heat-up rate.
d) The cure temperature must be kept constant. As a example, for a 200^{o}F wet layup repair this means that the temperature must be kept at 200^{o}F +/- 10^{o}F for the required dwell time of 220-250 minutes.

e) After the required cure dwell is finished, the temperature of the heat blanket must be decreased at a rate of 5^{o}F per minute until a temperature of less than 125^{o}F has been reached.

f) Print out the cure parameters, i.e. time, temperature and vacuum profiles for repair records, and for post-repair quality assessment

g) Release the vacuum pressure and remove the vacuum bag and heating equipment.

H3: Describe the critical steps necessary for inspecting a completed bonded repair, including NDI and interpretation of results

a) After the hot bonding equipment and vacuum bag, breather plies and parting films have been removed, the cured repair is first visually inspected for anomalies. The inspector will use a flash light or intensive light source to aid in his visual perusal of the bonded repair. He will be looking for any discolored areas or indications such as bubbles or bulges that may indicate an anomaly within the repair patch or the repair bondline. A visual inspection of fiberglass repair patches can very often reveal areas of disbonds or delaminations due to the transparent nature of the cured patches. Carbon repairs are less revealing of anomalies to visual inspection because of the color and lack of transparency of the carbon fibers.

b) The repair will then be NDI inspected using the tap hammer and/or Pulse Echo ultrasonic equipment. For laminate parts and sandwich parts with face sheets of more than 2-3 plies, it is recommended that, if available, the NDI inspection should be performed using the Pulse Echo technique. If no defects are detected, or any detected anomalies (e.g. porosity or delaminations) are within acceptable limits, then the repair is considered acceptable. If any anomalies are detected, they must be compared to any allowable bonded repair defect limits that have been established for the specific component in the source documentation. A printed record of the ultrasonic scan of the repair is helpful if this capability is available. It is useful that, if available, this post-repair inspection information be added to that recorded during the cure cycle and retained for the component repair log.

c) If the repair is found defective (i.e. any detected anomalies or defects are judged to be outside acceptable limits such as allowed processing anomaly limits), the repair must be removed and a new repair prepared and cured in its place.

d) If the repair is found satisfactory, any required protective coatings are to be restored to the repaired area (e.g. primer, enamel paint and any conductive coating such as aluminum flame spray or aluminum mesh installed for lightning protection, or an isolation coating such as a glass fabric ply).

e) The repaired component is returned to service.

H4 [LAB #2]: Demonstrate, and have students perform various damage assessments, including visual inspection, tap test and ultrasonic inspection

Students will participate in performing various NDI assessments of damaged panels in a controlled laboratory environment. The damaged panels will include those damaged in Laboratory #1, and several other configured panels, both sandwich and stiffened laminate panels. The inspection techniques to be used will be a) visual inspection, b) the tap test and c) a pulse echo ultrasonic inspection method.

Laboratory #2 Equipment List:
Two damaged configured panels, one sandwich and one laminate stiffened
Nine flat laminate panels damaged in Laboratory #1
8 Tap coins
Pulse Echo (P/E) instrument and transducer
Liquid get couplant
1 black marker pen
8 sets of blue and red marker pens

A video clip of the instructor inflicting damage to the two configured panels will be shown. The damage to these panels will be different than the damage that the students inflicted on their flat laminate panels in Laboratory #1. The intent of the video is for the students to gain a feel for differing damage sources and their effects on configured aircraft composite structural components.

The instructor will then demonstrate three inspection techniques on the two damaged configured panels.
He will first inspect the damaged areas of both panels visually using a flash light to enhance his inspection capability. He will map the periphery of the damages as best he can based on his visual inspections using the black marker pen.

Next he will demonstrate the use of the tap coin or hammer and the P/E instrument in mapping damage on the thin faced sandwich panel. He will use a blue marker pen to outline the periphery of the damage mapped using the tap coin, and a red marker pen to outline the periphery of the damages mapped with the P/E instrument. It is anticipated that there will be little difference in indications of the damage periphery showing that the tap coin is a reliable NDI technique for mapping damage on thin-faced sandwich panels.

Next, the instructor will demonstrate the use of the tap coin and the P/E instrument in mapping the damage on a laminate stiffened panel. He will again outline the damage periphery mapped with the tap coin with a blue marker pen, and the damage periphery mapped using the P/E instrument with a red marker pen. It is anticipated that the use of the P/E instrument will result in a larger mapped damage periphery than the tap hammer. This is due to the thicker laminate and presence of the stiffener on the backside of the panel. This demonstration will show that for increased laminate thickness and the presence of sub-structure, the P/E instrument is a more reliable NDI technique.

The demonstration will show that visual inspection is a useful inspection technique for initial damage detection, but is not appropriate for mapping damages.

Placeholder for a Video clip showing an actual inspection process of damaged configured parts during a maintenance event.

The instructor will then demonstrate the use of: 1) the tap test and 2) the Pulse Echo equipment for mapping the damage of one of the flat laminate panels damaged in Laboratory #1.

The instructor will outline the extent of the damage after the use of each NDI technique. He will then show the differences in damage outlines from the use of a) the visual inspection of Lab #1, b) the tap test, and c) the Pulse Echo ultrasonic technique. It is anticipated that the damage periphery indicated by the tap coin or hammer will be larger than that indicated visually, and the damage periphery indicated by P/E will be the largest.

When the instructor is satisfied that the students are familiar with the use of the NDI equipment, each student will assess and map the extent of the damage on one laminate panel damaged in Laboratory #1 using 1) the tap test, and 2) the pulse echo ultrasonic equipment as follows:

Inspection Instructions:

1) Inspect the front surface of the test panel using the tap coin or hammer to assess the extent of the damage already indicated by the black marker from Laboratory #1.
2) Mark the perimeter of the damage area indicated by use of the tap coin or hammer on the front surface of the panel with the blue marker pen
3) Next smear liquid gel over the front surface damage area
4) Inspect the front surface of the test panel using the pulse echo equipment and transducer, moving the transducer on the liquid gel.
5) As the P/E instrument indicates the damage perimeter, clean away the gel and indicate the perimeter with spots using the red marker pen. When the damage area is surrounded, clean off all of the gel and link up the red spots with a continuous red line
6) Compare the damage areas indicated by the black, blue and red markers.

H4 [LAB #4]: Demonstrate, and have students perform various post-repair acceptance inspections, including visual inspection, tap test and ultrasonic inspection

Students will participate in performing various NDI assessments of bonded repairs to laminate panels in a controlled laboratory environment. The repaired panels are those repaired in Laboratory #3. The inspection techniques to be used will be a) visual inspection, b) the tap test and c) a pulse echo ultrasonic inspection method.

Laboratory #4 Equipment List:
Nine flat laminate panels repaired in Laboratory #3
8 Flash lights
8 Tap coins
Pulse Echo (P/E) instrument and transducer
Liquid get couplant
8 sets of black, blue and red marker pens

The instructor will first demonstrate how to effectively visually inspect the bonded repair of one of the laminate panels repaired during Laboratory #3. He will use the flash light to aid in his visual perusal of the bonded repair. He will be looking for any discolored areas or indications such as bubbles or bulges that may indicate an anomaly within the repair patch or the repair bondline.

The instructor will next demonstrate the use of: 1) the tap test and 2) the Pulse Echo equipment for inspecting the repaired area of the repaired flat laminate panel.

The instructor will outline the extent of any potential defects in the repair after the use of each inspection technique. He will then show any differences in potential defect outlines from the use of a) the visual inspection, b) the tap coin, and c) the Pulse Echo ultrasonic technique. It is anticipated that if defects are detected in the repair, the defect periphery indicated by the tap coin will be larger than that indicated visually, and the defect periphery indicated by P/E will be the largest.

When the instructor is satisfied that the students are familiar with the use of the NDI equipment, each student will assess the state of the bonded repair on one laminate panel repaired in Laboratory #3 using 1) visual means, 2) the tap coin and 3) pulse echo ultrasonic equipment as follows:

Inspection Instructions:

1) Inspect the surface of the repair on the laminate panel by visual means, using the flashlight as necessary to highlight any suspicious areas of the bonded repair. Look for any discolored areas or indications such as bulges or blisters that may indicate anomalies in the repair patch or bondline
2) Mark any suspicious areas with the black marker pen.
3) Inspect the surface of the repaired panel using the tap coin or hammer to inspect the entire repaired area of the laminate panel.
4) Mark any potential anomaly or defect detected using the tap coin with the blue marker pen.
5) Next smear liquid gel over the entire repaired area of the laminate panel
6) Inspect the repair surface of the test panel using the pulse echo equipment and transducer, moving the transducer on the liquid gel.
7) If the P/E instrument indicates any defect, clean away the gel and indicate the defect perimeter with dots using the red marker pen. When the defect area is

adequately surrounded by red dots, clean off all of the gel and link up the red dots with a continuous red line.

8) Compare any defect perimeters indicated by the black, blue and red markers.