Leaflet 51-170 Inspection of Composite Structures

1 Introduction

This leaflet provides general guidance for the inspection of composite aircraft structure (including repaired structure) for which no, or incomplete, manufacturer instruction exists.

The term 'composite structure' generally refers to structure manufactured from a very broad band of material types when used in aerospace applications, e.g. metal alloys, metallic honeycomb sandwich structure, fibre reinforced non-metallic matrix systems etc. For the purposes of this leaflet the term 'composite structure' refers to both monolithic and sandwich structures manufactured from fibre reinforced non-metallic matrix systems, e.g. Glass Fibre Reinforced Plastic (GFRP or GRP), Carbon Fibre Reinforced Plastic (CFRP) etc. Inspection guidance for metallic composite structure may be considered to have been given in part by CAP 562, Leaflet 51-50.

2 General

The use of composite materials has increased significantly during recent years, developing from simple minor structural applications, e.g. wing tip fairings (e.g. Cessna C172), to use in significant sections of Primary Structure, e.g. fuselage and wings (e.g. Europa and many gliders) to complete airframes (e.g. T67 and Grob 115). Therefore, inspector familiarity with these materials, and the significance and nature of any damage, has become increasingly important.

Composite materials comprise of more than one constituent material (inhomogenous), and exhibit net properties that differ from those of any one of the constituent materials. Such a composition tends to provide properties that vary with direction (anisotropic). These properties, when correctly engineered, provide for the often quoted benefits of composite materials, e.g. high stiffness to weight and strength to weight ratios etc. However, these properties also provide for the possibility of more types of damage than would be found in metallic structure, and each type of damage may carry a particular significance to the structure. Therefore, it becomes necessary for the inspector to be aware of these damage types, although composite structure is usually designed such that the same level of predominately visual inspection required for metallic structure will also be required for composite structure to ensure that safety is maintained, i.e. any damage that may remain undetected visually will not propagate between inspections to threaten ultimate load capability and fatigue life.

Structural deterioration may arise from various causes, e.g. wear and tear, load, environment etc, and can affect various parts of the structure according to the design of the aircraft and the use to which it is put. Therefore, this leaflet should be read in conjunction with the appropriate manufacturer’s publications and Maintenance Schedule for the aircraft concerned.

Although considerable guidance may be given in the appropriate publications as to suitable opportunities for inspecting normally inaccessible structures, experience should indicate to the operator further opportunities for such inspections which can be included in the Maintenance Schedule, e.g. when the wing tip is removed permitting access to the adjacent wing structure etc.

Furthermore, whenever unscheduled access has been gained to a part of the structure which is normally inaccessible, then advantage should also be taken of this dismantling to inspect all parts of the structure exposed. The need to exploit such opportunities for inspection will be more prevalent to composite structures, than to metallic structure, due to the possibilities of significant Barely Visible Damage (BVD) and externally Non-Visible Damage (NVD). Apart from the airworthiness aspects, these combined inspections could often be to the operators advantage, since they may obviate the need for future dismantling. Furthermore, damage may be detected at an earlier stage of development requiring a smaller, and less costly, repair.

3 Cleanliness

The propensity for composites to suffer BVD and NVD requires the use of effective cleaning processes prior to inspection. A clean paint surface could make the difference between locating BVD and not, i.e. NVD, e.g. when non-penetrating impact occurs. Subtle changes in light reflection can be the determining factor.

Composite materials, and the associated protective treatments, e.g. paint, gel coats, etc., may react in significantly different ways from one material system to the next when exposed to various cleaning agents and techniques. These reactions may also differ from those more frequently experienced by operators familiar with metallic structure and any of the associated surface treatments. Therefore, it is important that manufacturer's guidance is obtained regarding cleaning materials and methods prior to the start of the cleaning process. However, a generic cleaning procedure applicable to common composite material structure may comprise of:

3.1 **Gaining access** (see also CAP 562, Leaflet 51-50): This includes removal of all acoustic liners, thermal blankets etc., such that all surfaces can be made visible in adequate lighting, either directly or with the aid of suitable inspection devices, such as mirrors or boroscopes. Note that particular care is required when handling and accessing composite structures, e.g. removing panels, placing body weight on surfaces, tool handling etc., because this type of structure is vulnerable to damage resulting from such activity, particularly the control surfaces and trailing edges. Protective equipment such as mats and crawling boards should always be used when, and in accordance with, instructions specified by the aircraft manufacturer.

3.2 **Removal of obvious debris, loose paint, dirt etc.:** Loose paint should be removed with care to avoid damage to the composite surface. This may be achieved by hand sanding, e.g. using Grade 320 paper. Note that a primer paint of contrasting colour may have been used to mark the surface of the structural laminate. Any sanding beyond the primer layer will damage the fibres and matrix. The manufacturer should be consulted for guidance if large areas of paint are to be stripped. Blasting, e.g. Plastic Media Blasting etc, or chemical stripping methods should be considered to be unacceptable unless specifically permitted by the manufacturer. Most blasting media will damage the composite outer fibre and matrix layer, whilst the constituent materials in paint stripper, e.g. Methylene Chloride, can be particularly damaging to the matrix.

3.3 **Initial visual inspection:** There should be a preliminary inspection of all surfaces, edges, and joints and is intended to provide an approximate indication of the nature and extent of any damage. Typical defects which may be detected at this stage include cracks, holes, gouges, dents, edge delaminations, fastener hole damage, severe burns, and sealant damage. A careful initial inspection may allow for an earlier, and therefore less costly, 'scrap' decision to be made without wasting time and effort completing any further work.

3.4 **Cleaning:** Cleaning may be achieved simply by wiping the surface using a cloth moistened with a suitable degreasing agent, e.g. Methyl Ethyl Keytone (MEK), Isopropyl Alcohol (IPA) etc. A clean cloth should be used for each application of agent and for each removal of excess fluid and dirt respectively. Should a more thorough clean be required, e.g. using a mild detergent and water, then masking will be necessary to prevent further damage from cleaning agent ingress at the damage site. Masking should be completed using a compatible tape. The cleaning agent should be applied with a sponge, cloth, or similar non-metallic means of application, i.e. that which will not damage the surface. The structure may be rinsed using clean water. High pressure hot water jets, or steam, should not be used. The structure may be dried using a clean dry cloth. Drying can be accelerated using a clean dry compressed airflow. Typically this may be at temperatures up to 50°C for most materials that have been cured at elevated temperature. However, materials cured at room temperature (without elevated temperature post cure) should be treated with caution at lower temperatures, e.g. 30°C maximum.

All drain paths and drainage holes should be checked to ensure that they are clear of debris once cleaning has been completed.

3.5 **Visual inspection**: see Section 4.

The sequence above may form the preliminary stage of a repair action should defects be found.

4 Inspection Methods

Approximately 90% of all aviation inspections of composite structure are visual, often being complemented by a Tap Test. Many other inspection techniques are used by the aviation industry, e.g. Dye Penetrants, Bond Testers, Ultrasonic Inspection, Radiography, Mechanical Impedance, and Thermography. However, these methods tend to be used more by manufacturing industry and public transport operators, than by small aircraft operators, due to the relatively high cost of installation and operation. These techniques are often only used following the visual location of damage, or suspected damage. Details regarding these methods are available in many texts, and will only be briefly mentioned (Appendix 1) because they generally fall outside the scope of this Leaflet. Furthermore, Non-Destructive Inspection and Testing (NDI and NDT) are the subject of extensive research activity and consequently the material in this Leaflet does not attempt to be a comprehensive coverage of NDI and NDT.

All inspections must be completed by suitably qualified personnel, e.g. see CAP 747 Mandatory Requirements for Airworthiness Generic Requirement (GR) No. 23.

4.1 **Visual Inspection:** Some composite damage can be located by visual inspection, whilst some may not. Inspection may be complicated by the material surface finish. The material may remain in its natural finished state, it may have been finished with a dye, it may have a gel coat (possibly coloured), or it may have been painted. Paint colour may be significant to damage detectability. These conditions should be allowed for when completing inspection. Furthermore, knowledge of the surface material type, e.g. the type of weave etc, will help identify the existence of damage. Note that it is common for a manufacturer to use a sacrificial protective woven outer layer to protect the structural plies, particularly unidirectional plies. This may give a false impression of the structural build. Manufacturer's data, e.g. repair manuals, drawings etc, should be consulted to establish this point. If in doubt, then treat the outer ply as a structural ply.

Visual inspection may allow for the detection of many defect types, e.g. some impacts, delaminations, disbonds, cracks, some heat damage, 2·54mm (0·1in.) depth, scratches of 1·27mm (0·05in.) length etc. Lesser dimensions may be located in favourable conditions. The nature and extent of damage that may be detected may vary significantly, being a function of many variables, e.g. cleanliness, lighting, inspector skill and experience, surface finish, colour etc.

All visual inspections should be completed in adequate lighting, and at such a distance, that an inspector may be confident of locating damage as identified in Section 5. Manufacturer's instruction should be followed regarding the distance from the structure that an inspection should be completed because the nature and extent of inspectable damage should be a function of the design. Typically, a visual inspection should be completed at a distance no greater than 1·52m (5ft.) from the structure, whilst a detailed visual inspection should be completed at whatever lesser distance, e.g. typically 0·2-0·3m (8-12ins), allows confirmation of the existence, nature, and extent of any damage. This may be complemented using a 10X magnifying glass. Obviously, any suspicion of damage, or previous experience of damage at any given location, requires a detailed visual inspection and may require further disassembly. Particular attention should be paid to previous repair locations. Extensive disassembly may require aircraft jacking. Jacking should be completed in accordance with manufacturer's instruction.

The inspections may be completed with suitable inspection devices, such as mirrors, light probes and boroscopes, ref. CAP 562, Leaflet 51-50 Section 8 and Leaflet F-90.

Once located, the significance of the damage should be assessed, e.g. as being cosmetic or structural damage, see Section 5.

Note that visual inspection will not be adequate to allow detection of some damage types i.e. NVD, e.g. some delaminations, impacts, and heat damage etc. The design should allow for this, or further actions should be called in the manufacturer's data to deal with potential problems. Furthermore, note that some damaged structure may relax, e.g. impact damage, to the extent that 60%, or more, of the original profile may be recovered. Therefore, the time between a damage event and inspection may be significant to detectability.

4.2 **Light Test:** Delamination in GFRP components that do not have rigid foam, or any similar obstructions inside, can often be detected by pointing a bright light at the surface whilst looking at the other side. Damage may be evident as a dark area. Care must be taken in positioning the light source so as not to let the composite get hot, as this can cause damage. CFRP does not allow for such inspection. This is an inspection method widely used and recommended by manufacturers such as Grob and Slingsby.

4.3 **Tap Test:** In its crudest form the Tap Test is the simple tapping of the structure with a coin, or similar small hard blunt object, such that a sound is generated. A damaged structure usually produces a 'duller' sound than an undamaged structure. Although crude, the Tap Test can be a useful complimentary tool for a visual inspection, particularly when confirming the presence and approximate dimensions of disbonds and delaminations. It may be possible to detect such defects down to 12·7-25·7mm (0·5-1in.) diameter in typical composite manufactures. A structure should be explored in 6-13mm (0·25 – 0·5in.) steps to locate such damage. Note that the minimum detectable dimension increases with material thickness. The usefulness of the Tap Test for sandwich structure is limited to damage detection at the presented face, e.g. inter-ply delamination or core to skin disbond. Significant honeycomb cell fluid content may sometimes be detected. Unfortunately, the sound will also change due to factors other than damage, e.g. changes of thickness, hidden attached structure, potting material, the presence of repairs etc. Therefore, knowledge of the composite structure, and the surrounding structure, is necessary to gain the most useful information from the Tap Test. Furthermore, a Tap Test is difficult to use reliably over large areas because an inspector may experience problems maintaining concentration during such a repetitive task.

Note that automated electronic Tap Test equipment is available which measures impact signal transmission duration or frequency.

5 Damage

The significance of composite damage is dependent upon the function of the structure and the type and extent of damage. The most likely cause of damage, approximately 80%, is impact, often the result of ground handling. This may produce one, or more, of the damage types identified below. The most significant damage types are delamination, disbond and material penetration. The significance of the extent of damage is a function of the design. Reference should be made to manufacturer’s data regarding this issue.

5.1 **Structural Function:** The function of the structure depends upon the design. However, it is common for structure to be categorised as Primary Structure or lesser structure, e.g. Secondary Structure. Primary Structure is that which, if damaged, could threaten the structural integrity of the aircraft, e.g. wing spars, skins, ribs, ailerons, etc, or fuselage skins, stringers, etc, or tail structure, elevators, rudders, etc. Secondary Structure is that which may pose a significantly lower safety risk and/or be associated with an economic cost, e.g. wing/body fairings, nacelles etc. The categorisation may not always be clear, e.g. a fairing may initially appear to be Secondary Structure, but could, upon separation, threaten the safety of the aircraft by impact with Primary Structure. If in doubt, such structure should be treated as Primary Structure. Furthermore, the categorisation may be extended to distinguish between sections of any individual component, e.g. a flap may be 'zoned' such that structure adjacent to hinge attachments is considered to be more critical than the field areas, thus requiring more stringent allowable damage limits to be applied to the former. The inspector should use manufacturer’s guidance to clarify the function of the structure. This is particularly important for smaller aircraft designs because they tend to use a wider range of configurations than larger public transport aircraft.

5.2 **Types of Damage:** The type of structural damage, be it to Primary or lesser structure, may be categorised as **cosmetic** or **structural**.

5.2.1 **Cosmetic Damage:** Cosmetic damage is that which is of no immediate structural concern. However, cosmetic damage that could allow fluid ingress should be repaired, i.e. dried and sealed, to prevent it from progressing to become structural damage.

Wrinkling and Dimpling: Minor skin wrinkles and dimpling (sandwich panel skin wrinkling that adapts to the shape of the honeycomb cells, which should not be present if the part has been correctly designed with small honeycomb cells), Figures 1 and 2, may have been present since manufacture. Defects present from manufacture may be distinguished from damage by careful inspection for other evidence of degradation, e.g. surface crazing, fibre breakout, loose resin material, delamination etc. However, if in doubt, such structure should be Tap Tested for delamination to ensure that any apparent 'wrinkling and dimpling' is not the result of skin buckling, i.e. damage which is of structural interest.

Resin Rich and Resin Starved Areas: Porosity in resin rich areas, or exposed fibre in resin starved areas, Figures 3 and 4, should be obvious and must be dried and sealed to prevent long term degradation due to fluid ingress.

Surface Damage: Many structures use a sacrificial outer ply layer, e.g. a woven glass ply, to resist 'wear and tear' or to help prevent unidirectional fibre break out. The manufacturer's drawings should be referenced to avoid the incorrect determination of the significance of any surface ply damage. If any doubt exists regarding the function of the outer ply, then it should be treated as a structural ply and repaired accordingly. Damage to a sacrificial layer, although of no immediate concern, may allow fluid access to the main structure. Again, such damage should be dried and sealed.

5.2.2 **Structural Damage:** Structural damage is that which threatens the function of the structure, whether it be damage to Primary or lesser structure.

Composite structural damage may be further categorised as being **penetration damage**, damage between plies (**inter-ply damage**), or damage to the constituent materials (**intra-ply damage**), e.g. matrix or fibre damage. Sandwich structure adds further possibilities, e.g. honeycomb damage or core to skin interface damage.

5.2.2.1 **Penetration Damage:** Any laminate penetration, e.g. holes resulting from impact damage etc, is a concern because it represents damage to both fibre and matrix material. Such damage is often self evident, although smaller holes may be missed and could allow long term moisture ingress to occur. This is particularly true for sandwich structure. Any penetrations should be repaired.

5.2.2.2 **Structural Inter-Ply Damage:** Damage between plies.

Delamination: Delamination, Figure 5, is the separation between plies in a laminate, i.e. in the plane of the laminate. It may run across the whole laminate, or it may run to the laminate edges, and/or it may occur between many plies in any single laminate.

Composite structure is often compression critical. Delamination may further reduce the compressive strength, both at the local fibre level and at the component buckling level. Furthermore, delamination is often BVD, or NVD, on the external face of the structure. Therefore, thorough inspection of clean structure and access to the internal face of the structure is essential if the chances of detecting potentially significant damage are to be maximised.

Delamination may sometimes be visible as cracking parallel to the fibres at the laminate edges. Any cracked paint and debris at laminate edges should be removed, using non-metallic scrappers etc, prior to inspection of the edge.

Delamination that is not visible may sometimes also be located by using a Tap Test, see above. The chances of finding hidden delamination are greatly increased by knowledge of an event, e.g. an impact, or by the presence of other damage. Any fibre break-out on the internal face of the structure is likely to be associated with delamination. Any clues that indicate the presence of delamination, e.g. dents, paint damage, deformations, should by followed by a Tap Test.

Inspection for delamination should include all laminate edges, cutouts, and any opened fastener holes. Delamination resulting from poor fastener hole fit, wear and tear, poor drilling, or excessive fastener pull-up load is common.

Disbond: Disbond is the separation between laminates, e.g. a bonded joint, or the separation of a laminate skin from honeycomb core material, see 'Sandwich Structure Damage' paragraph 5.2.2.4.

Early detection of disbond is important because it may provide an indication of imminent joint failure. Obviously, this may be critical for any bonded Primary Structural joints that do not have secondary fastening. It should be noted that the progression from the initial areas of disbond to catastrophic failure may be very rapid. The progression may be accelerated by moisture ingress or fatigue loading at the joint.

Disbond may be evident as a gap in the adhesive line at the joint section edge, Figure 6, if accessible, or as ply peeling and/or paint damage along the joint edge when viewed perpendicular to the presented face. Disbond may sometimes be detected by using a Tap Test. Again, as with delamination, a 'duller' sound will be produced at the damage site than in the surrounding structure. However, interpretation may be difficult due to changes in section at the joint, varied back-up structure, and the presence of other joints.

Inspection of the disbond initiation surface, if visible, may help determine the potential severity of a problem. Correctly designed, the joint should fail in the adherend, i.e. the materials being joined together, because the joint should be stronger than the parent material. Such a failure, i.e. 'cohesive failure', will be evident as fractured matrix material and exposed and/or damaged fibres extending beyond the adhesive line into the adherend material. Such a failure is an indication of an overload. A more thorough inspection of the aircraft structure should be initiated, e.g. a 'heavy landing' inspection, unless the damage is the result of a known local event.

The disbond may be the result of a failure in the adhesive material, i.e. 'adhesive failure'. Fractured adhesive material may appear, probably without exposed fibres, to be paler in colour than the undamaged adhesive. Such a failure is an indication of an under strength adhesive.

The disbond may be the result of poor bonding between the adhesive and the adherend. This may appear as smooth unbroken adhesive and adherend surfaces without fibre exposure. Such a failure is potentially catastrophic because it may be the result of the adherend joint surfaces being contaminated. Such a contamination is very likely to have effected most, if not all, of a joint. Unlike an overload of a fully bonded joint, the material that has not already disbonded at the time of a finding is very likely to be poorly bonded. Such a finding must be followed by repair action that will recover full strength to the whole of the joint unless it can be shown that the remaining joint is at full strength, e.g. a small disbonded area is the result of a known local contamination.

5.2.2.3 **Structural Intra-Ply Damage:** Damage to the constituent materials.

Fibre Damage: Composite material fibres carry the laminate load via shear transfer from the matrix material. Therefore, the failure of any fibres may be significant to the strength of the part, particularly when tensile loads are parallel to the major fibre direction.

Fibre failure may be visibly evident as fibre breakout, Figure 7. The form of the fibre breakout will depend upon the fibre arrangement in the material, e.g. unidirectional, woven etc, and the strength of the fibre-matrix bond. Unidirectional material may often produce long fibre filament breakout, whilst woven materials, e.g. aramids, often result in fibre tufts standing proud of the surface. Such breakout may be evident across the material surface, along the structure edges, at cut-outs, or in fastener holes. Those composite systems with weak fibre-matrix bonding, e.g. aramids, tend to produce more loose fibre and tufts, when damaged, than may be evident in a system with a strong fibre matrix bond. The latter may result in a cleaner brittle failure. Such damage may be associated with extensive delamination. Fibre breakout is often the result of impact damage, poor handling, or poor drilling, and is more likely to be evident on the back face of the structure. Any fibre damage, particularly that to primary structure, must be repaired immediately.

Matrix Damage: Matrix material allows the transfer of load to and between fibres. Therefore, matrix material damage is potentially very serious. The failure of the matrix material may be particularly significant to the shear and compressive strengths, and stiffness, of a structure.

The matrix may be damaged by direct overload or by exposure to the environment, e.g. heat, moisture etc. The properties may be altered at the time of exposure to the environment and/or altered when exposed for a period of time. The alteration may be reversible or irreversible.

Heat Damage: Heat may soften the matrix such that shear and compressive strengths and stiffness are significantly reduced. If the heat is excessive, i.e. the glass transition temperature range (the temperature range over which a reversible change from brittle to rubbery state occurs) is exceeded, then irreversible damage may occur as the matrix breaks down (typically at a temperature above the cure temperature).

Heat damage may be evident as obviously burned and discoloured matrix material. However, other clues should also be used as indicators of heat damage because exposure to lesser heat may not discolour the matrix. Such clues include knowledge of any events, e.g. exposure to engine heat, blistered and discoloured paint, or gel coat damage etc.

Lightning Strike Damage: Lightning strike damage is a particularly severe form of heat damage which may be evident, assuming that total destruction has not occurred, as distinct 'pin-hole' burns at the lightning contact points, extensive damage (any and all types) remote from the contact point, e.g. delamination, and severe burns at junctions with metallic structure. Further clues may include damage to any attached conductive paths, e.g. aluminium 'window frames', or missing static wicks. The extremities of an aircraft are particularly vulnerable to lightning damage, e.g. wing tips, fins, control surfaces etc.

It should be noted that discoloration may not define the full extent of the matrix damage. It may be necessary to trim an additional margin from the cut-out area, e.g. 25-55mm (1-2 in.), to clear damaged matrix material that has exceeded the glass transition temperature, but which has not visibly burned. Alternatively, it may be possible to define the damage boundary by careful grinding of the trimmed cut-out edges until a change in texture is experienced. This process requires skill and judgement.

Any inspection for lightning damage should include a check of all electrical paths and contacts, including static discharge wicks, aluminium flame sprayed surfaces etc. It is essential that the integrity of the protection systems are maintained. Manufacturers tend to recommend the use of bond testers to check that the resistance of the system remains in limits.

Fluid Ingress: Fluid ingress may refer to both the uptake of fluid by the matrix or the uptake of free standing fluid, the latter being a particular problem with sandwich structure, see paragraph 5.2.2.4. Fluid ingress may degrade the matrix material resulting in strength reduction which, again, can be particularly significant for structure subject to shear and compressive loads. The extent of degradation will vary from one fluid to the next. Fluid, if not removed from the part, may make repair impossible due to part destruction if the repair cure temperature exceeds the fluid boiling point.

Fluid ingress may not be very obvious. However, any evidence of protective layer damage, e.g. to the paint, should raise suspicions and require that any subsequent repair action be preceded by drying action, see Section 3.4.

Heat and moisture combined may further enhance the degradation of the properties of a composite. Compressive and shear properties are lowest in the 'hot and wet' condition, e.g. a carbon epoxy system, 0·6% moisture content, may show 10-15% compressive strength reductions between room temperature and 50°C. Tensile properties are lowest in the cold and dry condition, e.g. a carbon epoxy system may show 5-10% tensile strength reduction between room temperature and -56°C.

Matrix Cracking: Matrix cracking may often be the first visible indication of potentially significant damage, e.g. it may be associated with delamination and may be evident at the laminate edge as regularly pitched cracks transverse to the major load direction. It may also be evident as surface crazing over the plan surface areas. The latter is more common to woven materials.

Porosity: Porosity, Figure 8, may allow fluid ingress and result in material degradation. It may be evident as local surface pitting. Severe internal porosity may sometimes be located using a Tap Test. The existence of porosity may also indicate that the local structure has excess resin or that a local repair exists. Porosity should be dried and sealed. However, severe porosity requires a more substantial repair.

Fibre-Matrix Disbond: A laminate manufactured from predominately unidirectional plies in many orientations may split parallel to fibres in some of the plies as the fibre disbonds from the matrix. This is typical of unidirectional CFRP and may not be too significant if the splitting occurs in a small number of plies laying perpendicular to the load direction. However, splitting may have a significant effect upon the stiffness and compressive strength in some designs, particularly those subject to bi-axial loading.

Such damage may be evident as cracking in the damaged plies at the laminate edge or as fibre breakout from the presented face. However, it should be noted that many designs avoid the use of unidirectional materials in the outer plies, thus reducing the opportunity of detecting such damage.

5.2.2.4 **Sandwich Structure Damage:** Sandwich structure comprises of a honeycomb, or foam, core sandwiched between skins.

The skins are thin laminates which have a similar function to that of an 'I-Beam' cap, i.e. resists bending. The core has a function similar to that of an 'I-Beam' web, i.e. resists shear, and also crushing loads. Therefore, the effects of damage can be considered accordingly.

Skin Damage: The laminate skins may suffer similar damage to that already described, e.g. delamination and disbond. However, the limited thickness, e.g. typical 3 or 5 plies, of the skins increases the likelihood of, and therefore importance of, detecting skin penetration because these damages allow access for free standing fluid to the cell structure of the core. Similarly, skin-core disbond at sandwich structure edges, Figure 9, may allow fluid ingress. A considerable amount of fluid may accumulate, Figure 10, creating weight and balance problems for control surfaces. Furthermore, the accumulated fluid may freeze, expand, and further damage the part. Any attempt to repair the part without drying will also be futile if the cure temperature is greater than the boiling point of the fluid. Total destruction of the part is likely.

Fluid ingress may sometimes be detected using a Tap Test, if the mass of free standing fluid is adequate to alter the sound transmission qualities of the structure. A Tap Test may also be used to detect near side skin-core disbond away from the edges of the structure.

Core Damage: Core damage is often obvious, e.g. Core Depression, Lateral Core Crushing, Figure 11, Skin Bulging, Dents etc. However, the skin may disbond from the crushed core and recover the original structural profile. Therefore, any suspicion of impact on a sandwich structure, e.g. missing paint, scratches, etc, should be followed by a Tap Test. Any damage should be dried and repaired.

5.2.2.5 **Structural Damage Causes:**

The above text identifies the majority of the basic damage types that may be experienced by composite structure. However, such damages may appear in many permutations depending upon the cause. Some causes have particular characteristics which are identified below, (other than impact which has already been mentioned).

Overload: This occurs if any of the primary failure strengths e.g. tensile, compressive, shear etc., are exceeded. Failure may also occur without exceeding any one of the primary strengths due to the interaction of stresses. The nature of the damage, e.g. fibre failure, delamination, matrix cracking etc, will depend upon the strength(s) exceeded. When failure occurs without exceeding any one of the primary strengths, damage may be evident as delamination because the stress interactions often result in out of plane stresses which exceed the out of plane strength (not normally considered a primary strength in many designs).

Fatigue: Contrary to popular belief, composite materials may suffer fatigue damage, particularly when damaged and exposed to the environment. Damage may also be evident as many permutations of the damage types identified in this leaflet. Fatigue damage is often evident throughout the life of the structure. Typically, damage may progress from initial transverse fibre-matrix disbond through intra-ply matrix cracking, inter-ply matrix cracking, delamination, and fibre failure. Engineering properties, e.g. stiffness and strength, reduce during this progression. This contrasts with metallic structure, which typically only shows evidence of fatigue damage during the final 5% of its life. Fastener locations in composite structure are particularly vulnerable to fatigue damage. Loose fasteners result in delamination, hole deformation, and sometimes heat damage. Note that composite structure failed in fatigue tends to show significantly more damage than a structure failed by comparable pseudo-static overload, e.g. typically up to ten times the number of damage sites. Knowledge of the existence of a fatigue environment and the above damage sequence should draw the inspector’s attention to the damage types identified and help the determination of damage significance. Again, any damage that is not obviously cosmetic requires immediate repair.

Lightning Strike Damage: Composite materials do not tend to be good conductors and consequently the energy from a lightning strike may be dissipated via complete, or partial, destruction of the part. Any combination of damage types identified above may be evident, but typically include obvious burns, various permutations of heat damage, and extensive delamination, see Section 5.2.2.3 above.

Wear and Tear: 'Wear and Tear' refers to general degradation such as fastener hole bearing damage, often the result of repeated panel removals, erosion of leading edges, minor ground handling damage, including abrasions, gouges, nicks and scratches etc. The significance of the damage must be assessed on a case by case basis and repaired accordingly. Such damage are usually self evident on a cleaned surface.

Ultra-Violet (UV) Radiation: Although not usually directly visible, UV damage may be evident through other damage types, e.g. matrix surface crazing, gel coat crazing etc. (note that some gel coats are partly intended to protect the composite from UV). UV damage reduces the engineering properties of the matrix material and makes it more vulnerable to load, the environment etc. Many of the older matrix systems are vulnerable to UV damage as are Aramid fibres. The damage severity increases with time exposure and altitude flown. Again, such damage should be repaired. Note that more recent matrix systems are more resistant to UV damage.

Abrasions, Gouges, Nicks, and Scratches: These may be of structural concern if fibres have been broken, particularly those parallel to the major load direction, or if a path for fluid ingress has been provided.

Existing Repairs: Repairs are structural discontinuities and will tend to provide unsymmetrical and unbalanced structure, thus making them a likely source of problems, e.g. repair ply peeling and delamination. Repairs tend to be more porous than the surrounding original structure.

Repair locations are usually obvious on unpainted structure, whilst the location of repairs on painted structure may be possible by careful visual inspection at a shallow angle to the clean surface. The identification of repairs may be eased by consulting the manufacturer's repair documentation which should provide some clues as to typical repair shapes, e.g. square, circular, etc, and typical repair styles, e.g. flush, scab doublers etc.

Obvious initial indications of degraded repairs include lifted paint and peeled repair doubler edges. Note that particular attention should be paid to recent repairs because a poor bond may well result in ply peeling, or possibly repair separation, within a short number of cycles.

A Tap Test may help to confirm the presence of a repair. Laminate repairs tend to have overlapped joint areas, additional plies, e.g. doublers etc, and increased porosity. Repaired sandwich structure tends to have extensive potting material around the repair boundary. These factors will alter the sonic response of the structure.

6 Repairs

Composite aircraft manufacturers may classify areas of the aircraft, usually Primary Structure, as non-repairable or no repairs permitted areas. These areas are usually detailed in the Maintenance Manual and/or the Flight Manual. If damage is located in these areas the manufacturer must be consulted immediately for advice. For areas where repairs are permitted the repair should be carried out strictly in accordance with the manufacturer's instructions and using approved data. Allowable repairs should be carried out only in a suitably clean environment where temperature and humidity controls can be maintained and using only the material specified in the approved data. Personnel carrying out repairs should be suitably qualified in composite repair techniques and be aware of the health hazards associated with working with resins, hardeners, solvents and composite material dust. Consideration should be given to the effect that the repair may have on aircraft Centre of Gravity limits. Repairs to composite flight control surfaces may require control surface balancing which should be accomplished strictly in accordance with the manufacturer's instructions.

Note that repairs may interfere with lightning protection systems. Ensure that any damaged or displaced systems are corrected in accordance with manufacturer's data.

7 Paint Finish

Manufacturers often specify colours and types of paint finish because composite materials, particularly older materials, are sensitive to heat and UV radiation damage.

Any change to aircraft paint scheme must be strictly in accordance with the manufacturer's instructions. Further information regarding paint schemes may be found in CAP 747, GR No. 10.

Appendix 1 Further NDT Techniques

Qualified Personnel: NDT inspection must be completed by suitably qualified personnel, CAA CAP 747 GR No. 23 provides some guidance in this matter.

Penetrants: Red dye-penetrant may be of limited use for surface damage detection in composite structure. Its use should be considered to be part of a destructive exploration of the part because the penetrant will be difficult, if not impossible, to remove and may contaminate and degrade the material. Furthermore, poorly finished surfaces may give rise to many false indications.

Bond Testers: Bond testers use ultrasonic signals to detect shifts in the through-thickness resonant frequency of a bonded joint to locate disbonds or poor cohesion. A coupling fluid is required.

Low frequency bond testers (<100kHz) operate by measuring the phase and amplitude of the signal returned from energy transmitted in a plate wave mode to determine the integrity, or otherwise, of the material. A coupling fluid is not required.

High frequency testers (25-500kHz) operate by passing narrow bandwidth standing ultrasonic wave signals into the material. Deviations in the measured resonant frequency indicate the presence of a defect. A coupling fluid is required. Materials may be inspected to a thickness of 0·5 in. Delaminations may be located down to 0·5in. diameter.

Ultrasonic Inspection: Ultrasonic inspection involves the detection of ultrasonic waves passed through the structure. The receiver may be on the opposite side of the structure to the transmitter, i.e. Through Transmission (TTU), or on the same side of the structure as the transmitter, i.e. Pulse Echo (PE).

TTU allows disbond, delamination, and crack detection in monolithic and sandwich structure. However, good access to both sides is required.

PE allows detection of similar damage in monolithic structure, but from one side of the structure. However, damage detection will be limited to the near face skins in sandwich structure. This technique is available in a portable form.

Ultrasonic inspection may be developed into a map of the part and its defects, i.e. C-Scan. The use of sophisticated processing and focused transceivers allows the development of the C-Scan into a three dimensional representation.

Radiography: Radiography is the passing of X-rays through a structure and the recording of the shadow from that structure onto film. The shadow is a function of part thickness, density, manufacture, and X-ray voltage.

Radiography may be useful for the detection of transverse cracking and fluid ingress (in sandwich structure).

Composites require low voltages due to the low material densities. The low difference in densities between constituent materials makes the contrast between materials, and contrast between material and damage, difficult. Penetrants may be used, but these tend to be unpleasant materials, e.g. Zinc Iodide, which cannot be removed from the composite. Furthermore, the structure may require working to get the penetrant to fully penetrate the damage. Other disadvantages include safety considerations, limited equipment access, cost, and the need for skilled interpretation.

Mechanical Impedance: This method uses changes in structural stiffness to detect damage, particularly disbond and delamination. The stiffness is a function of thickness, geometry, elastic variables and densities. The phase and amplitude of a transmitted sonic signal are measured. This method may provide accurate determination of the extent of damage. Inaccuracies may result from incorrect receiver alignment, resonance, and noise from other equipment.

Thermography: This method relies upon the detection of thermal gradients, i.e. using IR radiation, to locate defects. The factors affecting the inspection include surface temperature, surface emittance, surface reflectance, background temperature, and the energy differential.

Thermography may be very useful for the detection of moisture ingress, particularly in sandwich structure. Unfortunately, an energy source is required to create the thermal gradient, e.g. the part may need to be removed from the aircraft and heated in an oven, or an engine run may be necessary, or immediate access to an aircraft upon return from a high altitude flight may be required. Furthermore, the equipment is expensive, knowledge of the structure is required, and interpretative skills are necessary.

Moisture Meters: These devices may be used to detect moisture in GRP and arimid material. They use the radio frequency dielectric power loss attributed to an increase in the conductivity of the composite, due to moisture absorption, to measure moisture content. This method of moisture detection cannot be used with conductive fibres, e.g. carbon, and cannot be used local to metallic structure, e.g. embedded conductive lightning protection grids may give false indications.

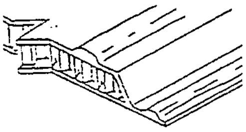

FIG.1 WRINKLED MATERIAL

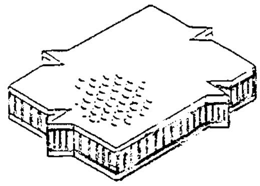

FIG.2 DIMPLING

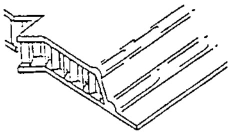

FIG.3 RESIN RICH MATERIAL

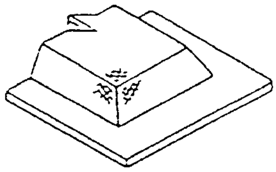

FIG.4 RESIN STARVED MATERIAL

FIG.5 DELAMINATION

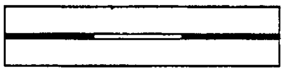

FIG.6 EDGE DELAMINATION

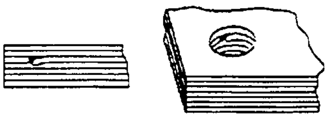

Fig.7 FIBRE BREAKOUT

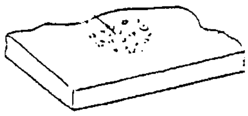

FIG.8 POROSITY

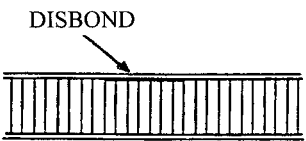

FIG.9 SKIN-CORE DISBOND

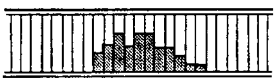

FIG.10 FLUID INGRESS

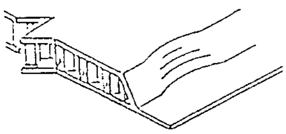

FIG.11 LATERAL CORE DENTING