FAA/EASA/Industry

Composite Damage Tolerance and Maintenance Workshop

Amsterdam, May 2007

EASA Perspective on Safe Maintenance Practice

- some regulatory concerns

S. Waite

EASA Perspective on Safe Maintenance Practice

Introduction

Content:

- Visual Inspection
(key part of F&DT and Maintenance)

- Certification
(examples of initial F&DT consideration)

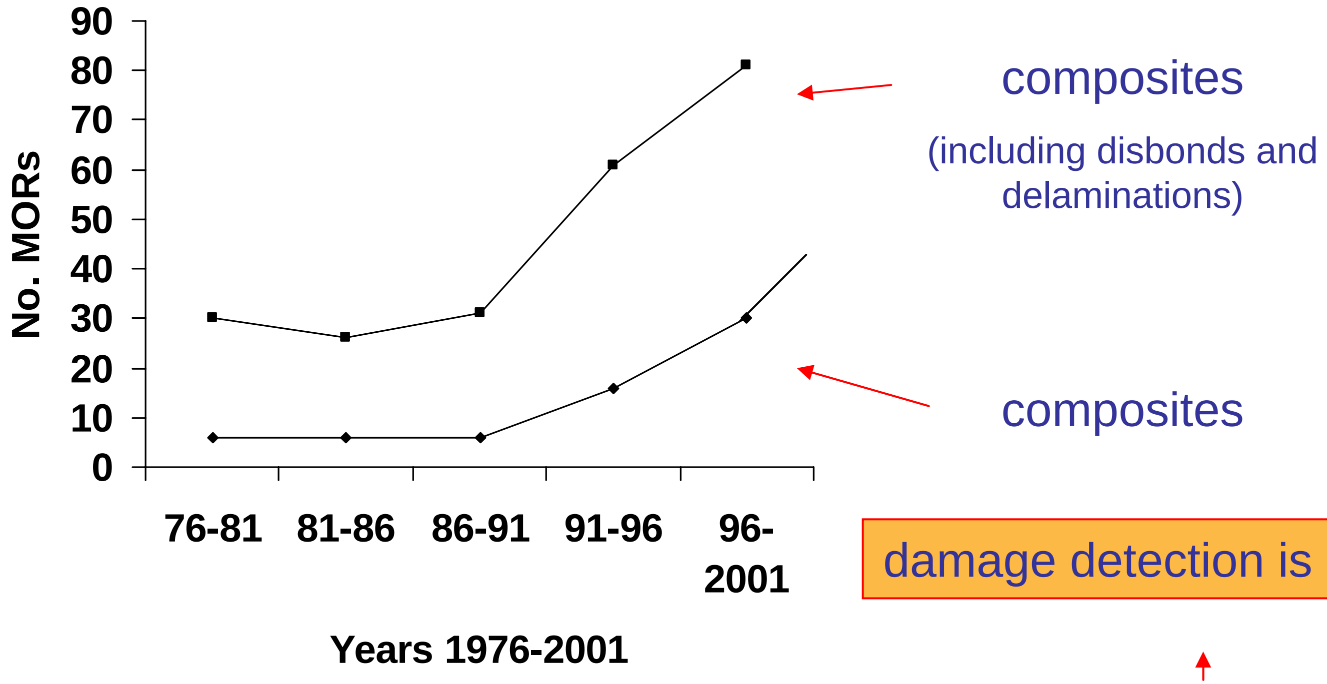
- CACRC Documents
(EASA position regarding use)

EASA Perspective on Safe Maintenance Practice

Introduction

Mandatory Occurrence Reports (MORS)

UK CAA composite issues, 5 year totals - increasing



damage detection is important

increased use of composites → increasing MORs → increasing safety concern

Visual Inspection of Composite Materials

Visual inspection is a key part of F&DT and Maintenance (and therefore safety)….

AC20-107A para.7(a)(2)/AMC No.1 to CS25.603 para.6.2.2:

‘The extent of initially detectable damage should be established and be consistent with the inspection techniques employed during manufacture and in service’

Also, until our experience and confidence increases….

- composites should match, or better, the behaviour of metallic structure

Visual Inspection of Composite Materials

Understanding visual inspection and damage detection in composite structure is becoming increasingly important because…..

- 80-90% inspections visual (unlikely to change much – Structural Health Monitoring?)

- increasing use of composites in exposed primary structure, e.g. fuselage
(previous used in protected and/or secondary and/or over designed structure)

- many new and varied paint schemes/decals & frequent changes
(low cost airlines)

Visual Inspection of Composite Materials

- recent missed/misinterpreted ‘large damage’ events?

- guidance materials now allow ‘slow growth’ and ‘’arrested growth’ - adds dynamic element to importance of inspection with respect to ‘no-growth’ – e.g. AC29-2C MG8

We already know that…..

- composites are notorious for BVID/NVD

- relaxation may limit chances of finding damage

Visual Inspection of Composite Materials

What are we trying to find?

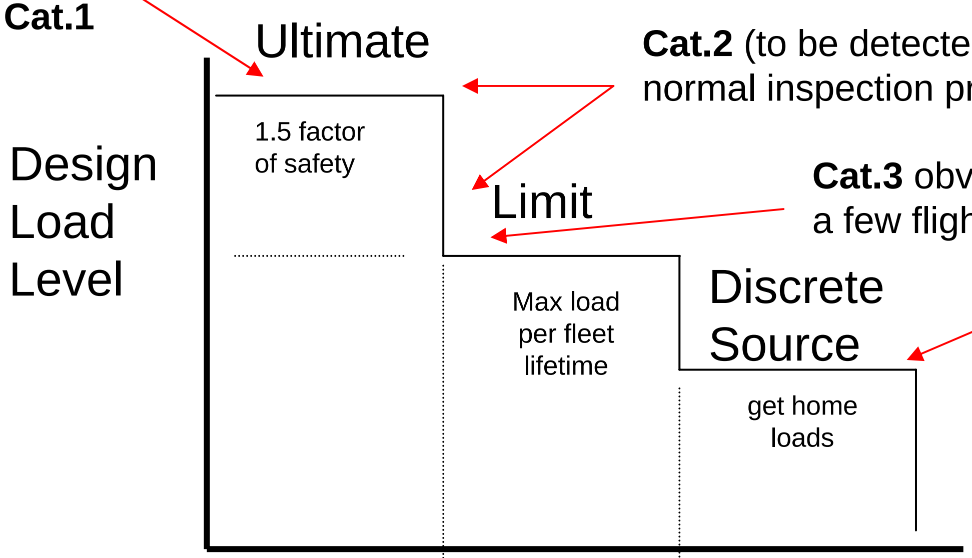
Design Load and Damage Considerations for Durability & Design (from MIL-17 Fig. 7.2.1(a))

BVID, Allowable Damage, etc, **Cat.1**

Cat.2 (to be detected and repaired – normal inspection process)

Cat.3 obvious in a few flights

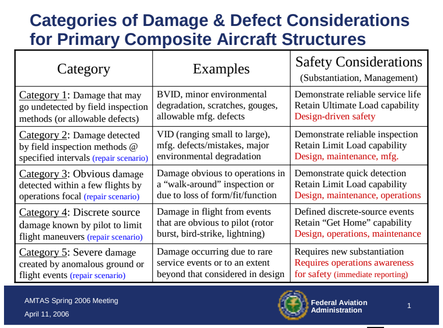
e.g. bird strike, rotor burst, lightning– **Cat. 4**



(**ADL**) Allowable Damage (**CDT**) Critical Damage Threshold

Increasing damage size

What is Cat.5 – hidden Cat.2,3,4?



Categories of Damage & Defect Considerations for Primary Composite Aircraft Structures

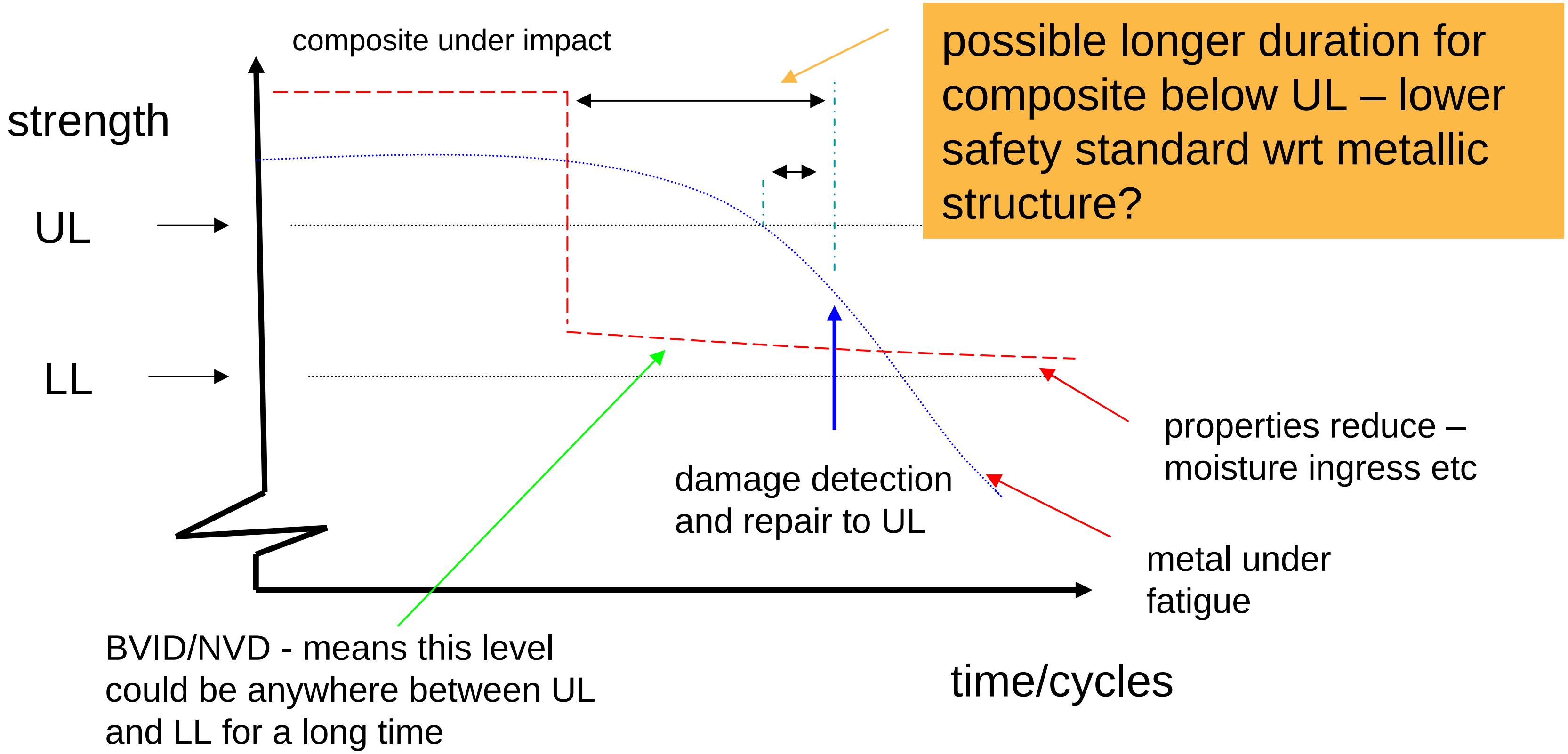
Category	Examples	Safety Considerations (Substantiation, Management)
Category 1: Damage that may go undetected by field inspection methods (or allowable defects)	BVID, minor environmental degradation, scratches, gouges, allowable mfg. defects	Demonstrate reliable service life Retain Ultimate Load capability Design-driven safety
Category 2: Damage detected by field inspection methods @ specified intervals (repair scenario)	VID (ranging small to large), mfg. defects/mistakes, major environmental degradation	Demonstrate reliable inspection Retain Limit Load capability Design, maintenance, mfg.
Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)	Damage obvious to operations in a “walk-around” inspection or due to loss of form/fit/function	Demonstrate quick detection Retain Limit Load capability Design, maintenance, operations
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)	Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning)	Defined discrete-source events Retain “Get Home” capability Design, operations, maintenance
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	Damage occurring due to rare service events or to an extent beyond that considered in design	Requires new substantiation Requires operations awareness for safety (immediate reporting)

AMTAS Spring 2006 Meeting
April 11, 2006
Federal Aviation Administration 1

Visual Inspection of Composite Materials

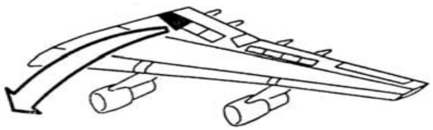
What are we trying to find?

Comparison of Composite Non-Growing Damage and Metal Fatigue Crack Damage UL-LL (from Mil-17 fig.7.2.2.2(c))



Visual Inspection of Composite Materials

What are we trying to find?



Examples: Inboard Flying Panel

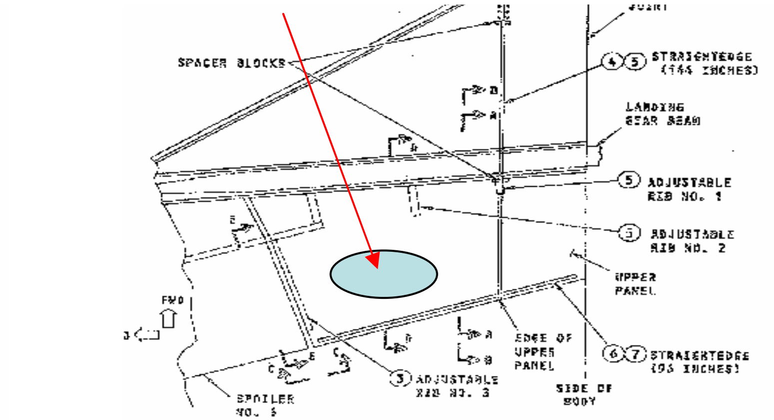
- Cat.3 or 4?

(use existing experience in the absence of much exposed primary structure experience)

- **moderate/severe vibration - 2 ‘air turnbacks’**
- **ground inspections - no findings**
- **pulsating upper skin to core delamination witnessed in flight**
- 24 inch x 60 inch disbond

Damage - sometimes obvious… sometimes not

(SB747-57-2261)

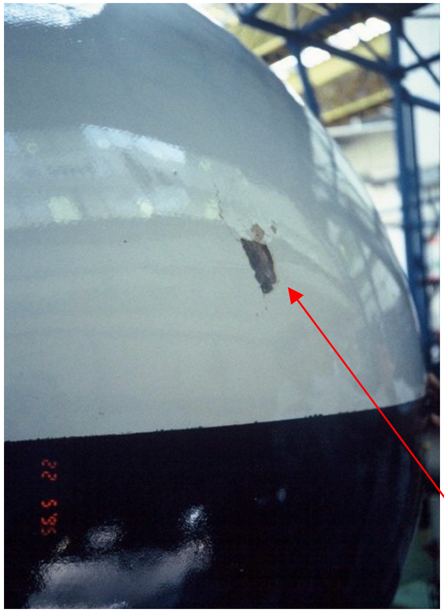


Example: LARGE NON-VISIBLE DAMAGE

Visual Inspection of Composite Materials

What are we trying to find?

Examples: Radome – Cat. 3 or 4? evident within a few flights – visible /equipment failure.



Radome – Bird Strike - usually minor concern

categorisation is debatable, but understood and detectable

Visual Inspection of Composite Materials

What are we trying to find?

Note: Damage to 'Non-Primary' Structure can hazardous or catastrophic
(Note: composites reduce part count, but increased part size)

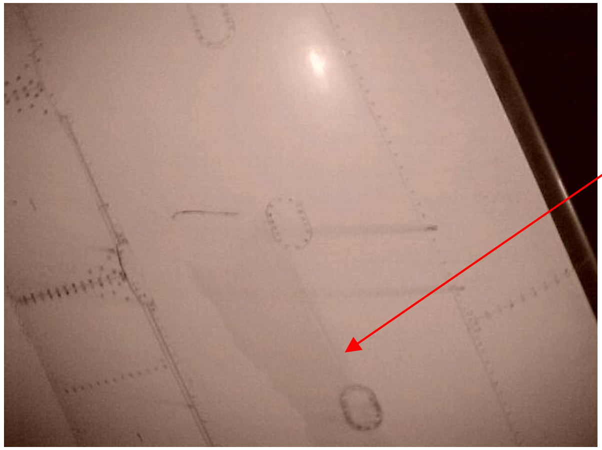
- hail destroys radome
- debris enters engine

- bird penetrated nose fairing (< 4lb bird, but > Vc)
- 'ram air' lifted nose, loss of control (now modified)

Visual Inspection of Composite Materials

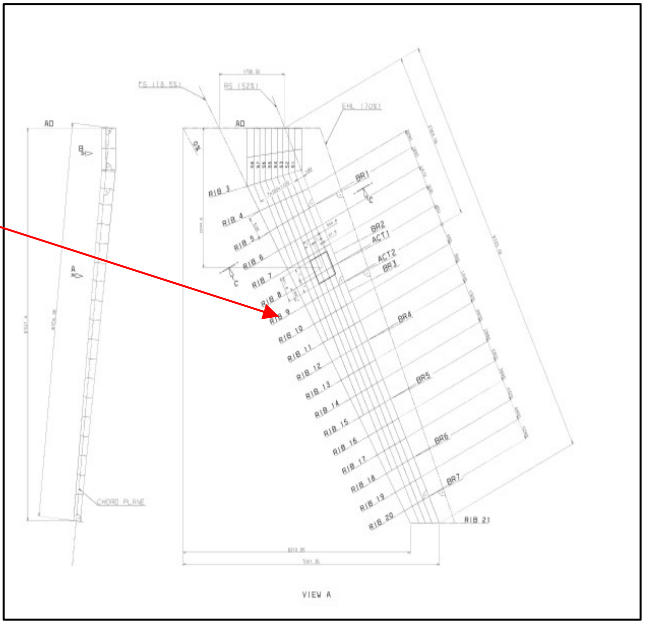
What do we do when we find damage?

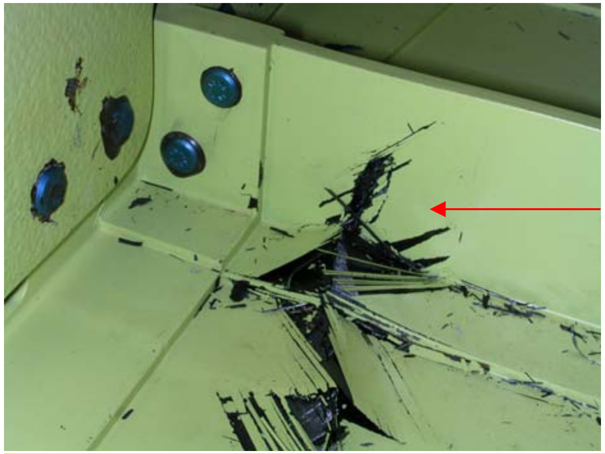
Examples: Horizontal Stab - Cat.5?



-**damage detected but not followed up**

-aircraft returned to service





- subsequent inspection – severed spar and skin
- probable cause – upstream access cover separation/impact

ONCE DAMAGE IS DETECTED

FOLLOW-UP ACTION IS IMPORTANT

Visual Inspection of Composite Materials

Blame Culture

- damage expensive for operators
- pressure transferred to ground crew

→

Example (metallic) : B757
- 8 in. gash in pressure hull not reported
- detected during climb – no pressurisation
- returned safely - lucky

Problem: Composites are potentially worse than metallic structure

- damage may not be evident (BVID/BVOD/NVD – relaxation etc)
- easier to convince yourself no problem exists
- easier to walk away

Operators must:
- reduce Blame Culture
- train ground crews properly

→

All damage must be reported

Visual Inspection of Composite Materials
Signal Detection Theory*

How does visual inspection, and follow up action, work for composites?

Visual inspection of structures for damage is an exercise in signal detection

- **Correctly detected damage - a 'hit'**
- **Failing to detect damage - a 'miss'**
- **Misdiagnosing a mark on a surface constitutes a 'false alarm'**

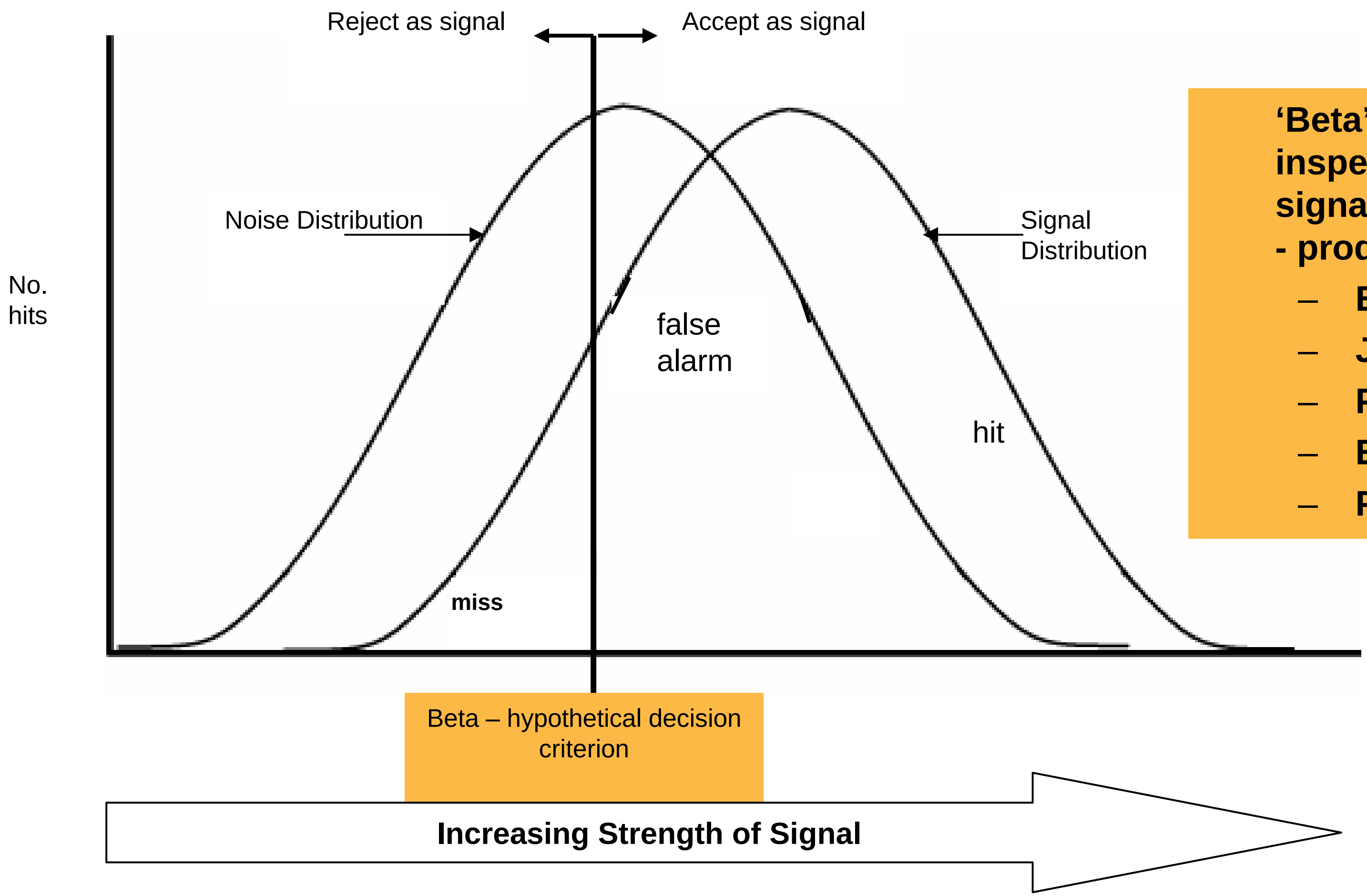
Visual search can only produce one type of error - a 'miss'
'false alarms' are the product of subsequent decision errors

'signal' distribution - damage that the inspector detects. Some signals are:

- **strong (large, obvious damage)**
- **weak (e.g. small surface blemishes that indicate damage on the blind side)**

'noise' distribution - surface scratches, discoloured paint, dirt, paint finish, environmental conditions, poor light

Visual Inspection of Composite Materials
Signal Detection Theory



'Beta' - criterion inspector designates signal as being a 'hit' - product of :

- **Experience**
- **Job instructions**
- **Part criticality**
- **Expectations**
- **Personal biases**

Visual Inspection of Composite Materials
Signal Detection Theory

Starting point for analysis (scheduled or pilot report) **– influencing factors**

- limited environment, distance, lighting, equipment
- inspectors need to know which panels are composite
- some inspectors don't believe that they will see damage on composites (survey)

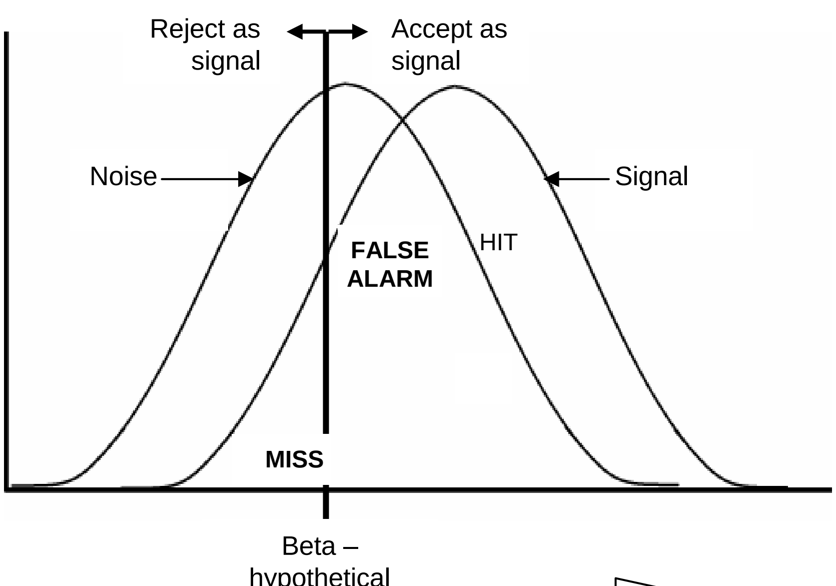
Decision Making - follow up actions (forms of signal conditioning)

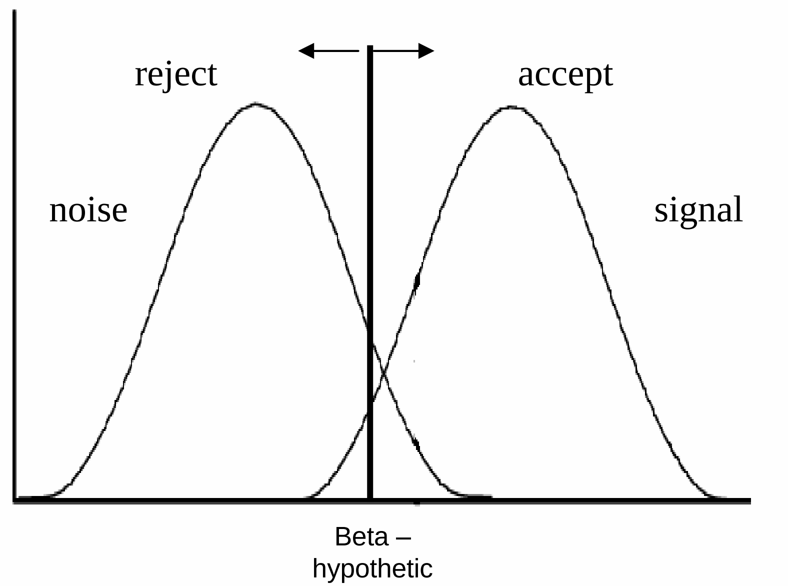
- change the visual distance, angle, lighting, cleanliness etc
- tactile tests - tap test, touch test etc
- internal Inspection

* strengthen the 'signal' (damaged) component & filter the 'noise'

Visual Inspection of Composite Materials
Signal Detection Theory (re-visited)

Tactile Test moves noise towards reject





Increasing Strength of Signal

Signal Detection Theory could:

- **provide a tool to help us quantify and understand visual inspection, and follow up, processes**
- **form part of an inspector training course**

Visual Inspection of Composite Materials

issues that may be important: Colour/Finish

- BVID not usually a design driver (captured by larger damages through the damage no-growth design philosophy)

- however, there is uncertainty regarding Cat.5 impactor geometry, energy levels, in flight load levels etc,

- best damage metric unclear (dent not necessarily the issue)

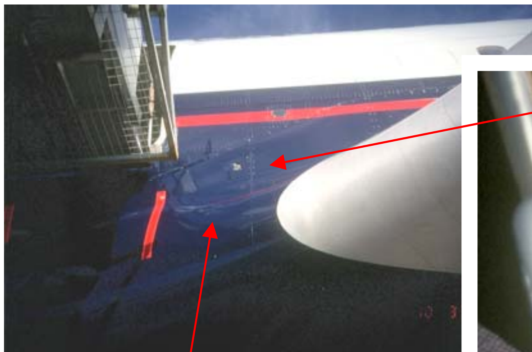
- Therefore, need to optimise what we do understand to minimise the chances of missing damage until we have more experience

Understanding colour/finish at the BVID level could still be beneficial
(relatively, if not absolutely – until experience/understanding improves)

Visual Inspection of Composite Materials

issues that may be important: Colour/Finish

impact point (damage reported)



damage or reflection?

(frame broken – not shown)

colour & finish can be important for damage detection

Visual Inspection of Composite Materials

issues that may be important: Colour/Finish

Example: (not just a composites issue):

BA B747 Lap Joint ‘Pillowing’
- aging aircraft issue 1992 - corrosion between skin lap joints

-**visual inspection** for ‘pillowing’ required

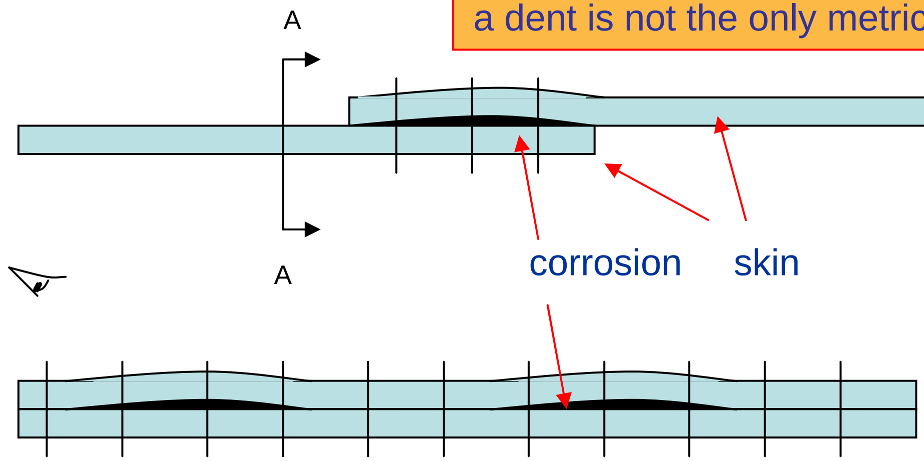
-if found, use NDT (and/or open lap):

New Gloss Blue - **very reflective - excessive ‘indications’ of defects** - unnecessary follow-up NDT - some joints opened - ‘no fault founds’ (subsequent ‘cry wolf’ problem)

Old Matt Blue - **few indications**

– what was missed?

a dent is not the only metric



Lap Joint View A-A

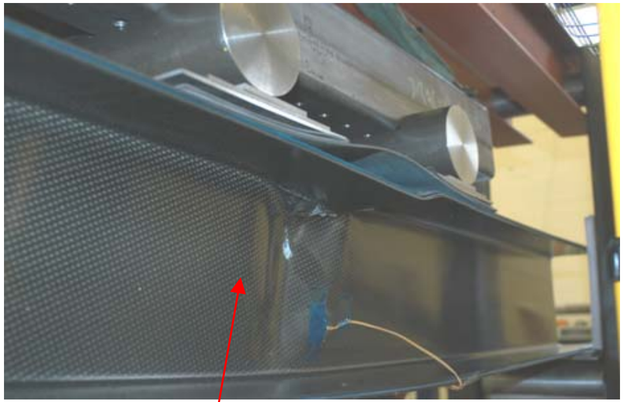
Light, colour, and finish can make this difficult to find

Visual Inspection of Composite Materials important issues: Preload/Damage

Do unloaded and loaded composite structures present similar damage when impacted?

- damage area produced by impact was reduced by preload

- residual strength of the impacted preloaded structure was reduced by as much as 50% with respect to unloaded structure (failure mode not significantly changed)



carbon composite 'C' section structure, both unloaded and preloaded, impacted with 0.25kg birds at 70-80 m/s

Ability to detect damage and the residual strength were reduced by preload.

How do we account for this in visual inspection and DT assumptions?

European Aviation Safety Agency

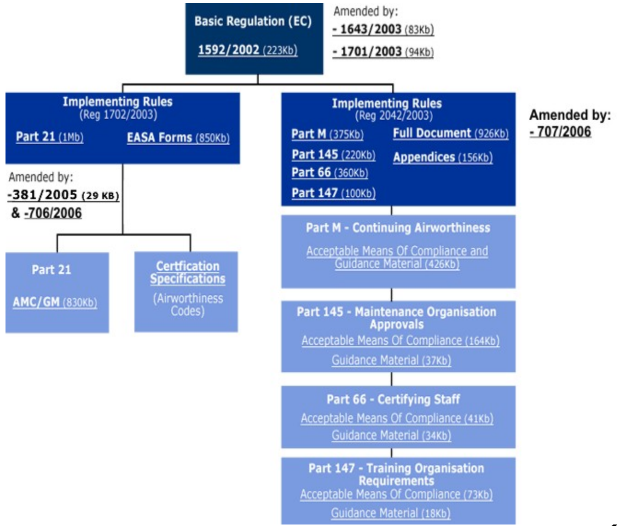
How are regulations evolving to manage composites – Certification

Certification is the process by which an applicant produces, and shows formally to the certifying agency, the records to prove that any given design, or product, has satisfied all of the appropriate requirements

Certification applies to Design, Production, and Airworthiness (Initial and Continued Airworthiness) – all closely linked

Regulatory Agencies address F&DT and Maintenance during Design Certification

Inspection critical to Certification ………



How are regulations evolving to manage composites – Certification

Examples – Initial Certification Link to F&DT and Maintenance:

CS 25.1529: Instructions for Continued Airworthiness:
'Instructions for Continued Airworthiness in accordance with Appendix H …. must be prepared'

CS 25.571: Damage Tolerance and Fatigue Evaluation of Structure:

'(3)…..inspections or other procedures must be established as necessary to prevent catastrophic failure, and must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 25.1529'

How are regulations evolving to manage composites – Certification – CRI

Certification agencies use a range of tools at Initial Certification, e.g. SCs, NPRM, NPA, CRIs, IPs, etc, to supplement basic code, e.g. CS25 amdt. 2. (when technology runs ahead of requirements, or clarification of interpretation of Means of Compliance (MOCs) is necessary)

e.g. Certification Review Item used to:

- review (MOC)
- call up Special Conditions/Notice of Proposed Amendment (SCs/NPAs) (forms part of Cert. Basis)
- address unusual/new features

  e.g. due to technology changes

Composite F&DT and Maintenance CRIs raised for:

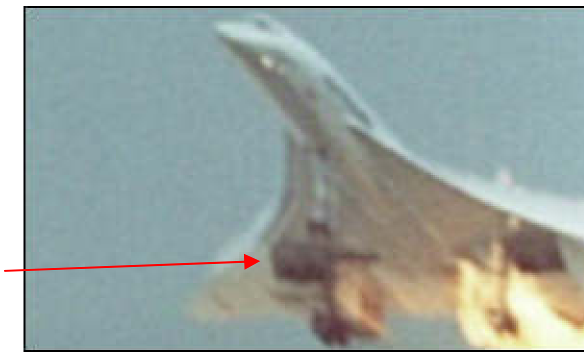
Tyre/Engine Debris, Lightning Strike, Fire

How are regulations evolving to manage composites – Certification – CRIs

Example CRI: Engine/Tyre Debris

- ***Manchester accident***, ***engine debris penetrates access panel*** *– fuel leak and fire -* ***debris significant***

- ***Concorde accident*** *,* ***tyre debris induced wing skin failure*** *and fire* ***– configuration detail significant*** *(thin metallic skin, high wheel speed, large tyre debris)*



Experience: metallic wing skin structure of conventional configuration and thickness has provided few problems

Note: existing requirements 25.901, 903, 963, AC20-128A, NPA 25E-304 already consider low energy engine and tyre debris with respect to access covers and/or fuel tanks

How are regulations evolving to manage composites – Certification

- composites can suffer large blunt BVID/NVID
(consider wing surround structure and define correct metrics)

CRIs raised:

Engine Debris - investigate MOC (higher performance engine, larger/faster 'small debris')

Tyre Debris - SC to include wing surround structure (extend 25.963(g))
- include other structure (fuselage - NLG),

- define metric and make explicit link to CS 25.571

F&DT and maintenance issues

How are regulations evolving to manage composites – Certification

Example CRI: Lightning (see AC 20-53B, AC20-136A, AC 20-155)

- composites do not conduct electricity as well as metal
(1000 times more resistant)

- destroys structure

- finds alternative path
(electrical, hydraulic systems)

- arcing

S76 North Sea lightning strike 1999 - repaired

AAIB

composite blade maintenance
- F&DT safety issue

S76 North Sea accident 2001

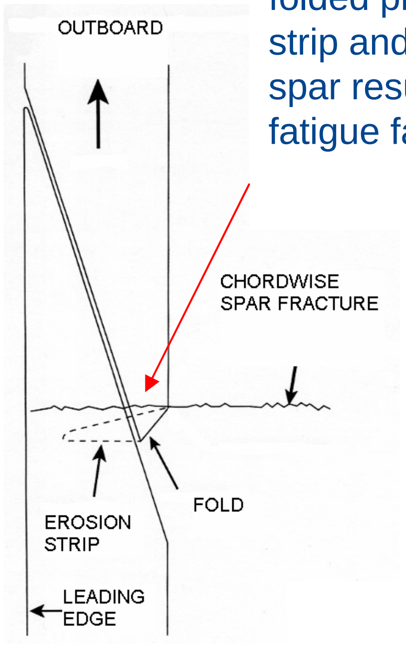
Figure 14: Showing the recovered helicopter onboard MSV Stadive without its main rotor head and main gearbox assembly which detached during the first associated 'lift' from the seabed and was recovered before the main airframe structure shown here.

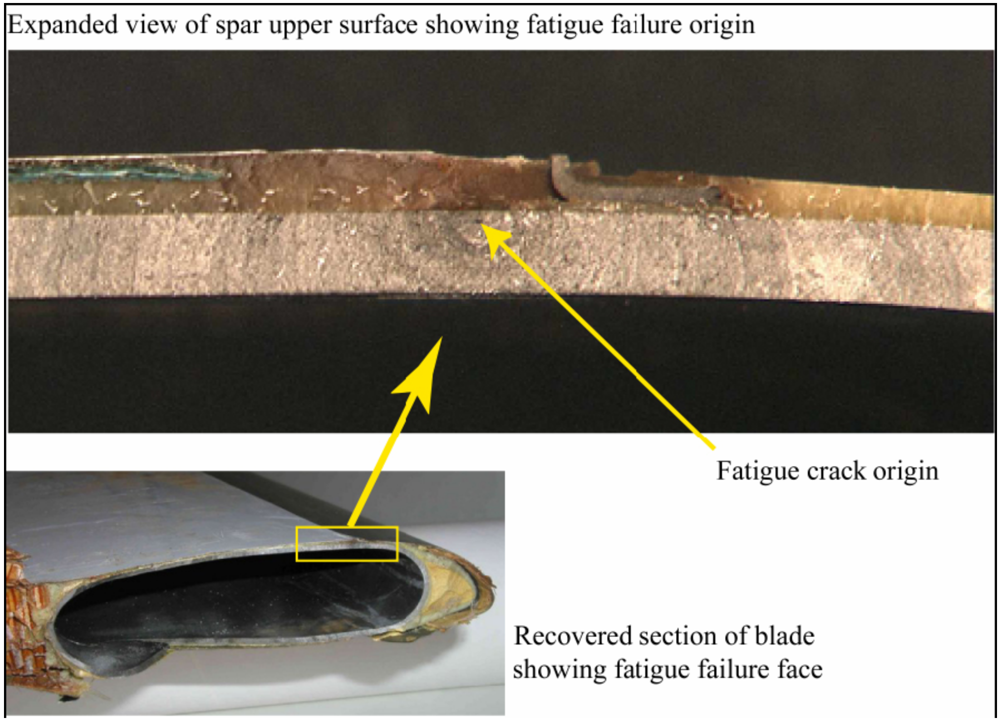
How are regulations evolving to manage composites – Certification

Composite blade lightning strike, and repair, became a metallic F&DT issue

production/repair detail is important

arc between folded protection strip and blade spar resulting in fatigue failure





How are regulations evolving to manage composites – Certification

composite does not conduct heat as well as metal

CRI raised:

detail important

- MOC with respect to 25.981 & 954
(overlaps flammability issues, auto-ignition temp etc)
- multi-layered protection – including sealed fasteners,
(reduce ignition sources, further to meshes, 'window frames' etc)
- damage should be visually obvious externally
    - discrete source damage
    - characterize undetectable damage (integrate into 25.571)

F&DT and maintenance issues

CACRC and Related Data
Regulatory View…

Repairs and Approved Data:

Background: The Regulations……..

EASA Part M ‘Continuing Airworthiness’: M.A.304 Data for modification/repairs:

‘Damage shall be assessed and modifications and repairs carried out using data approved by the Agency or by an approved Part 21 DO’

EASA Part 145 ‘Maintenance Organisation Approval’

Form 1 ‘Authorising Release Certificate’ – Block 12 data – text entry options:

‘modified’ and ‘repaired’ shall be supported by approved standards*

* manufacturing/design/maintenance/quality standard approved by a competent authority

CACRC and Related Data
Regulatory View…

EASA Part 21 Subpart M 'Repairs': allows Major repair…

'Major repair' includes

21.A.91 GM:

(ii) Changes to materials, processes or methods of manufacture of primary structural elements….

(iii) Changes that affect F&DT or life limit cycles

(iv) Changes that affect aeroelastic characteristics

Many repairs to primary composite structure and/or outside OEM limits will affect one or more of the above……..

CACRC and Related Data Regulatory View…

EASA Part 21 Subpart M 'Repairs': allows Major repair development subject to satisfying conditions including……

21.A.432: Capability: MO can develop major repair if it has DOA (Design Organisation Approval) – Part 21 Subpart J (with appropriate scope)*

21.A.433: Repair Design: DO must satisfy TC/STC Certification Basis

- does the MO/DO have this data, including the Means of Compliance (MOC)?

21.A.435: Classification: DO to classify 'major' and 'minor' repair correctly

* MO can request TC/STC holder or DO (with appropriate scope of approval) to develop repair

CACRC and Related Data Regulatory View…

- important message

- significantly more difficult to accept major repair to composite structure from non-OEM DO (without OEM support), relative to metallic structure,

- DO less likely to have adequate data - close link between the details of the production/repair process and the developed design properties, e.g., F&DT behaviour, Allowable Damage Limits (ADLs), impact of developed repair upon existing surround structure etc

- larger more integrated parts, typical of composite design, makes correct repair classification more difficult, e.g. poor extended field repair to secondary structure could be a threat upon failure, separation, and impact with other structure.

CACRC and Related Data Regulatory View…

Few Composite specific rules for Training - Maintenance:

EASA Part 66

66.A.45 Type/task training and ratings
(only identifies generic subject areas)

6.3 Aircraft Materials — Composite and Non-Metallic

6.3.1 *Composite and non-metallic other than wood and fabric….*

training content guide good
– industry, authority supported

SAE Aerospace
An SAE International Group

AEROSPACE INFORMATION REPORT	AIRxxxx	
	Issued	Proposed Draft (Date) (OrigDate)
	Revised	

Teaching Points for an Awareness Class on
"Critical Issues in Composite Maintenance and Repair"

1. SCOPE:
The following document has been generated by the ATA/IATA/SAE Commercial Aircraft Composite Repair Committee (CACRC) and provides the essential curricula for conducting classroom and laboratory sessions for a Critical Issues in Composite Maintenance and Repair class.

1.1 Purpose:
The purpose of this AIR is to provide the terminal course objectives and teaching points necessary for conducting a Critical Issues in Composite Maintenance and Repair class. When an entity offering this type of course teaches each of the subjects of this document according to its Terminal Course Objectives (TCO's) and Teaching Points, then the course shall be deemed to be in compliance with this document.

2. REFERENCES:
AIR4844B : Composites and Metal Bonding Glossary
AIR4938 : Composite and Bonded Structure Technician/Specialist: Training Document
AIR5278 : Composite and Bonded Structure Engineers: Training Document
AIR5279 : Composite and Bonded Structure Inspector: Training Document
R-336 Care and Repair of Advanced Composites, 2nd Ed.
ARP5089 : Composite Repair Ndt/Ndi Handbook
AE-27 : Design of Durable, Repairable, and Maintainable Aircraft Composites

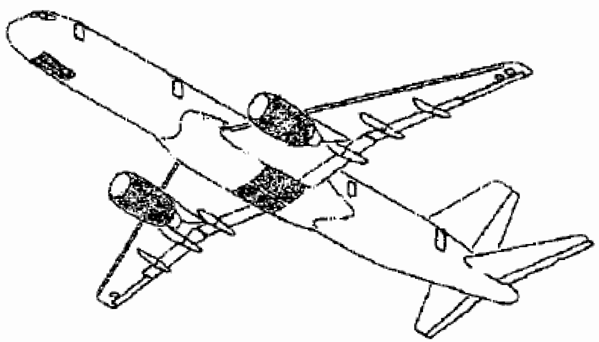
3. Base Knowledge
This base knowledge subject is provided to those students having limited exposure and/or understanding of materials science. Prior to the exposure to critical issues involved with the maintenance and repair of composite materials in commercial aerospace applications (Part II below), the student must understand the fundamentals of the technology to enhance learning. This subject will provide an overview of maintenance and repair, to be later reinforced in Part II below in detail. Included in this topic is: 1) a description of basic materials technology and terms, 2) an introduction to maintenance and repair, 3) other critical elements, such as coatings and selection criteria for bolted and bonded repairs, and 4) developments in materials research regarding maintenance and repair.

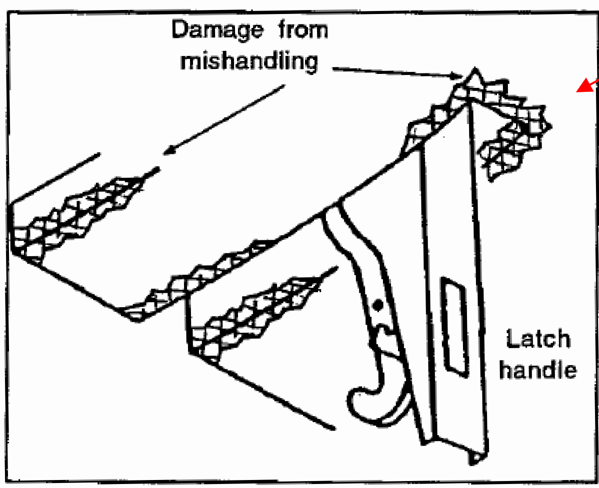
3.1 After completing this unit, the student will *understand the basics of composite materials technology.*
This material is intended to provide fundamental concepts and vernacular to the student with minimal exposure to composites' technology. Terminologies, material applications, processing, and properties are covered at a summary level. For students requiring this level of knowledge, this content is best taught as a first topic in the awareness course.

3.1.1 The student will be able to distinguish among resin, fiber and core applications and uses.

3.1.2 The student will be able to describe various composite processing parameters.

CACRC and Related Data Regulatory View…



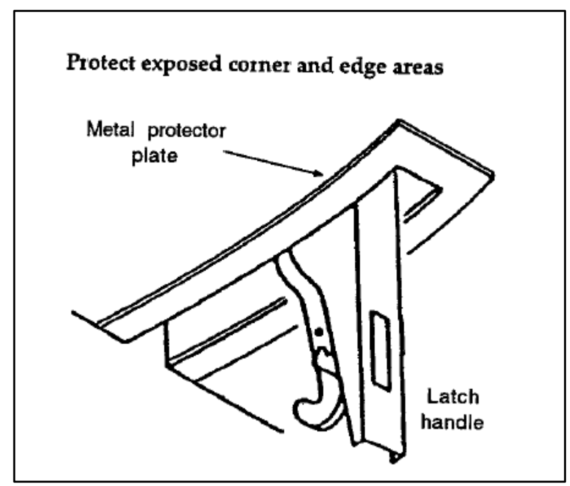


problem

solution

good practice recognised

SAE/CACRC Guidance:
e.g. AE-27: Design of Durable, Repairable, and Maintainable Aircraft Composites



CACRC and Related Data
Regulatory View…

But,

Data applied to Primary Structure, PSEs, Large Secondary Structure (which could separate and impact such structure) must be approved by the appropriate authority, e.g. OEM, in accordance with the regulatory framework,

- particularly NDI, repair design methodologies etc

Conclusion: EASA recognises, and gives credit to, appropriate use of the CACRC (and related) documents, but only within the regulatory framework, e.g. as a recognised reference

Note: EASA is considering a change to the definition of what constitutes AMC and GM materials

EASA Perspective on Safe Maintenance Practice

Conclusions

Safety Messages:

1/ Visual inspection - important for Certification, F&DT, and Maintenance issue

we need to:
- characterise damage (and the threat)
- identify the key metrics
- understand inspection and damage detection

(including - colour/finish, preload - under EASA investigation)

2/ Cat.5 damage - difficult to detect (more so than metallic structure)

- operators must develop 'blame free culture'
- all events must be reported

(not a new message, but worth repeating)

EASA Perspective on Safe Maintenance Practice

Conclusions

Safety Messages:

3/ Training – consider Human Factors (raise awareness of bias etc)

4/ Certification Regulations and Guidance Materials are evolving (during Initial Airworthiness process) to address important F&DT and Maintenance issues

– essential for the safe use of composites
(material properties generated in production/repair processes
– detail important)

5/ Many CACRC (and related), documents recognised by EASA. However,

must be used within regulatory framework

Conclusions

Finally – an inspectors quote*:

"…if the inspection needs to be conducted during a particularly windy evening, I will have to place my cherry picker at a greater than the normal distance in order to avoid an impact of this with the aircraft, which will be moving due to the wind. However from such a distance I might not be able to detect all the existing defects. […] if the sun is shining very brightly into my eyes and I am trying to inspect the rudder I might miss something during that particular inspection"

* *The inspection of aircraft composite structures: a Signal Detection Theory-based framework' A.Psymouli, D. Harris, & P. Irving, Cranfield University, UK*

ANY QUESTIONS?