Damage/Defect Types and Inspection - some regulatory concerns

MIL-17 Damage Tolerance and Maintenance Workshop
Chicago July 2006

Visual Inspection of Composite Materials

Visual Inspection of Composite Materials

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’

Visual Inspection of Composite Materials

Why is it becoming increasingly important to understand the visual inspection and detection of damage in composite structure?

- 80-90% inspections visual (unlikely to change much)

- 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 paint schemes/frequent changes (low cost airlines)
  (How important is Colour/Finish to damage detection?)

- recent missed/misinterpreted 'large damage' events**?**(A300 rudder/A330 Stab)

- 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

Visual Inspection of Composite Materials

We already know that…..

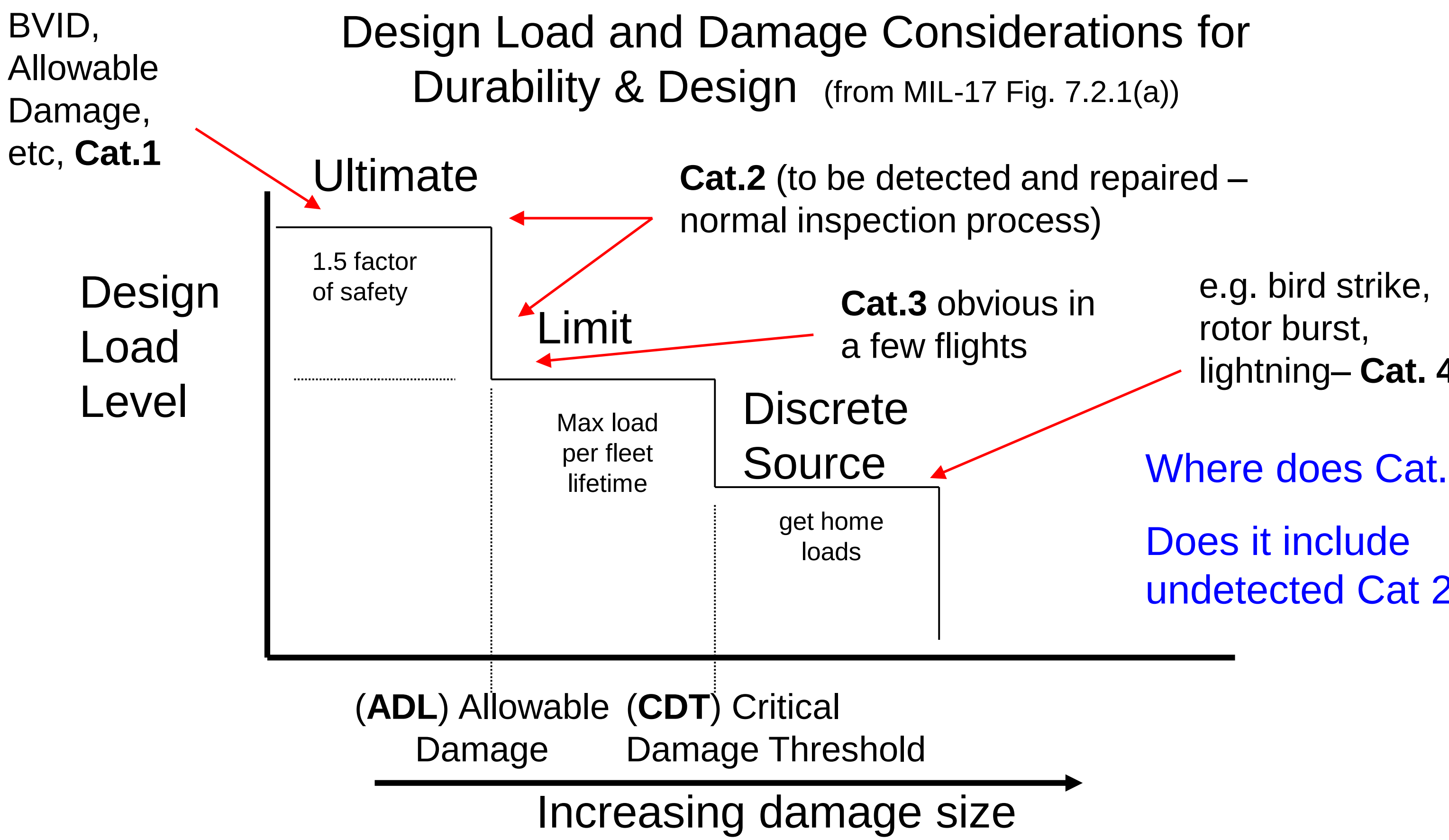
- composites are notorious for BVID/NVD
- relaxation may limit chances of finding damage

Also, we need to show that composites match, or better, the behaviour of metallic structure. Are we making 'metal head' assumptions when showing compliance with requirements (for requirements not obviously composite related – i.e. as listed in AC 20-107A)?

- do unloaded and loaded composite structures present similar damage when impacted? (real structures are usually subjected to preload when impacted)
- does internal structure require special consideration? (is a dropped tool more significant in a composite structure and can the damage be found?)

Visual Inspection of Composite Materials

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



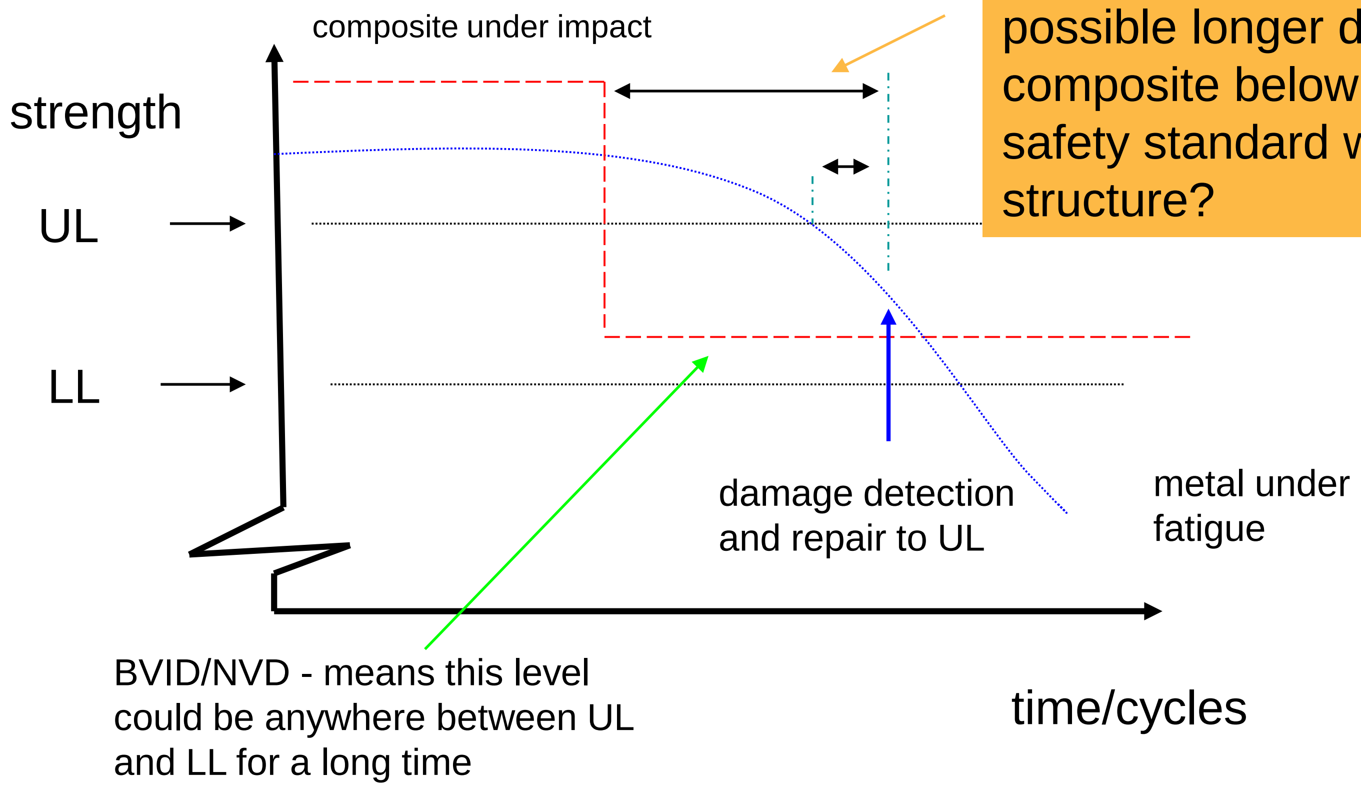
Where does Cat.5 fit ?

Does it include undetected Cat 2,3,4?

Visual Inspection of Composite Materials

Visual Inspection of Composite Materials

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

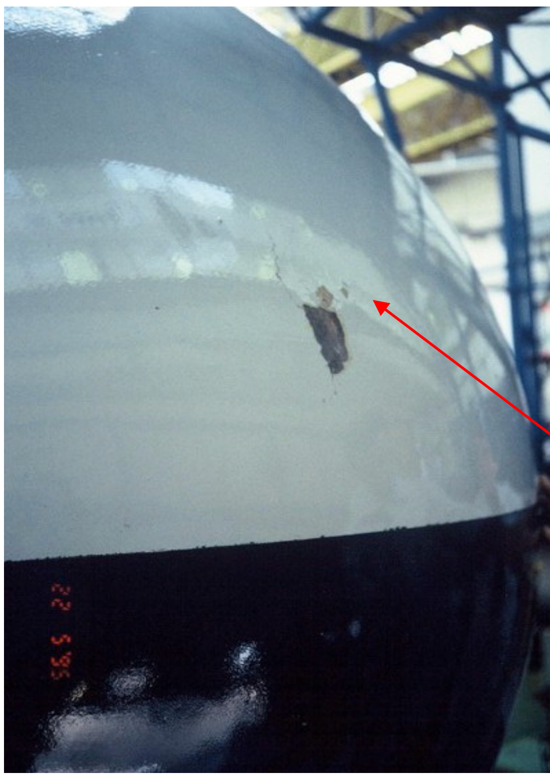


possible longer duration for composite below UL – lower safety standard wrt metallic structure?

Visual Inspection of Composite Materials

Examples: Radome – although not necessarily primary structure (could be catastrophic if it separates). May be evident to pilot as equipment failure.

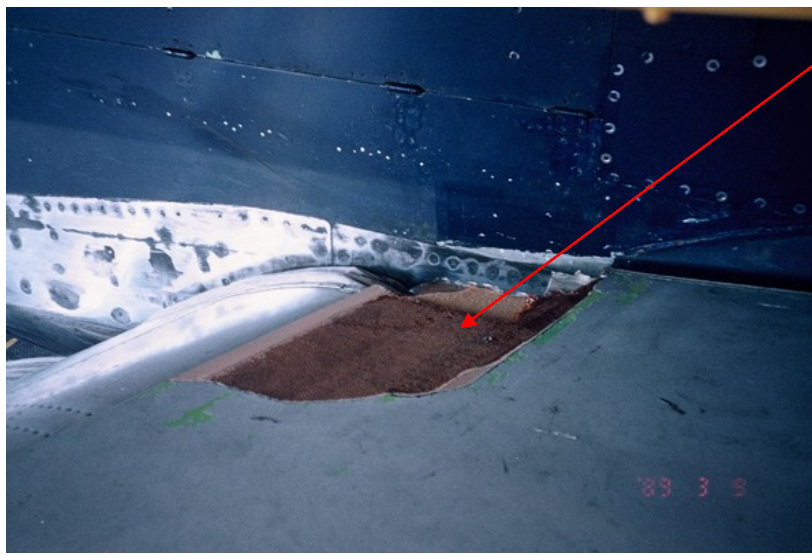
Cat. 3 or 4?



Radome – Bird Strike - although details of categorisation are debatable it is understood and detectable

Visual Inspection of Composite Materials

Examples: Inboard Flying Panel - Cat.3 or 4?



not primary structure,

-sometimes not evident to pilot

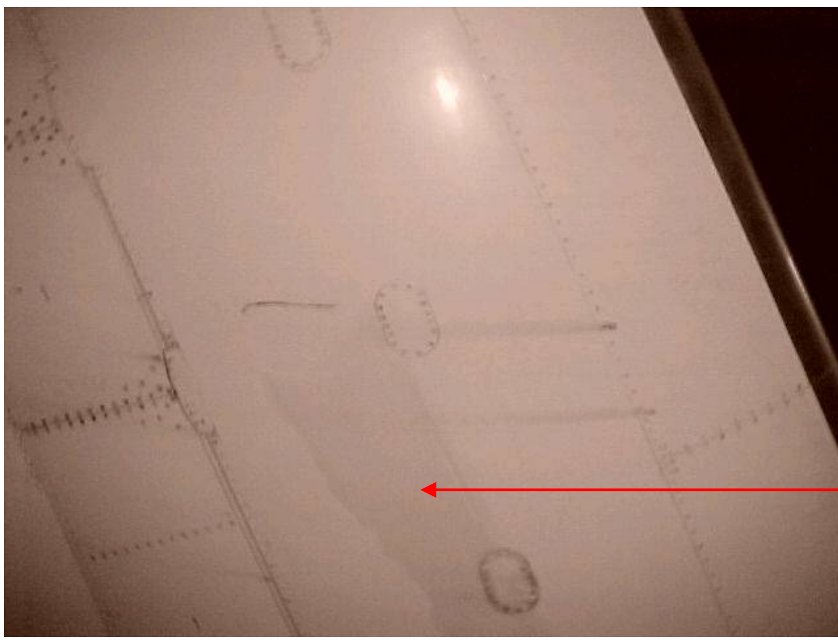
-sometimes moderate/severe vibration

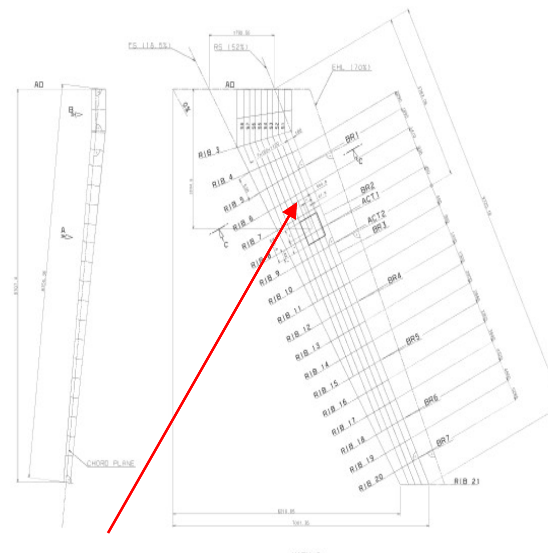
-sometimes evident to passengers!

Inboard Flying Panel – partial separation
(SB747-57-2261)

Visual Inspection of Composite Materials

Examples: A330 Horizontal Stab - Cat.5?





damage initially detected but not followed up - aircraft returned to service

Visual Inspection of Composite Materials

Examples: Horizontal Stab - Cat.5?

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

Visual Inspection of Composite Materials

What is the Cat.5 problem - (assuming that an event has not been reported!)? - In order to solve a problem we need to first define and bound it

We need to:

1/ find damage in operational situations – limited time, environment, and equipment – visual inspection most likely - What are we looking for? Is BVID a useful metric? If so what influences this?

2/ determine how bad the problem is – visual plus follow up – tap test etc

Therefore, we need to understand:

How does visual inspection, and follow up action, work for composites?
Can we get more out of a visual inspection?

Visual Inspection of Composite Materials
Signal Detection Theory*

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

- **Correctly detected damage can be categorised as a ‘hit’**
- **Failing to detect damage can be categorised as a ‘miss’**
- **Misdiagnosing a mark on a surface in this context constitutes a ‘false alarm’**

Visual search can only produce one type of error, that of a ‘miss’

‘false alarms’ are the product of subsequent decision errors

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

Visual Inspection of Composite Materials
Signal Detection Theory

		damage exists	
		yes	no
damage detected	yes	Hit	False Alarm
	no	Miss	Correct Rejection

Visual Inspection of Composite Materials
Signal Detection Theory

The '<u>signal</u>' distribution consists of damage to the composite structures of the aircraft that the inspector is required to detect

- **Some signals will be 'strong' (large, obvious damage)**
- **Some will be weak (for example small surface blemishes that denote delamination of the composite on the back of the panel)**

The '<u>noise</u>' distribution consists of surface scratches, discoloured paint, dirt, paint finish, environmental conditions, (rain droplets etc), poor light

Visual Inspection of Composite Materials
Signal Detection Theory

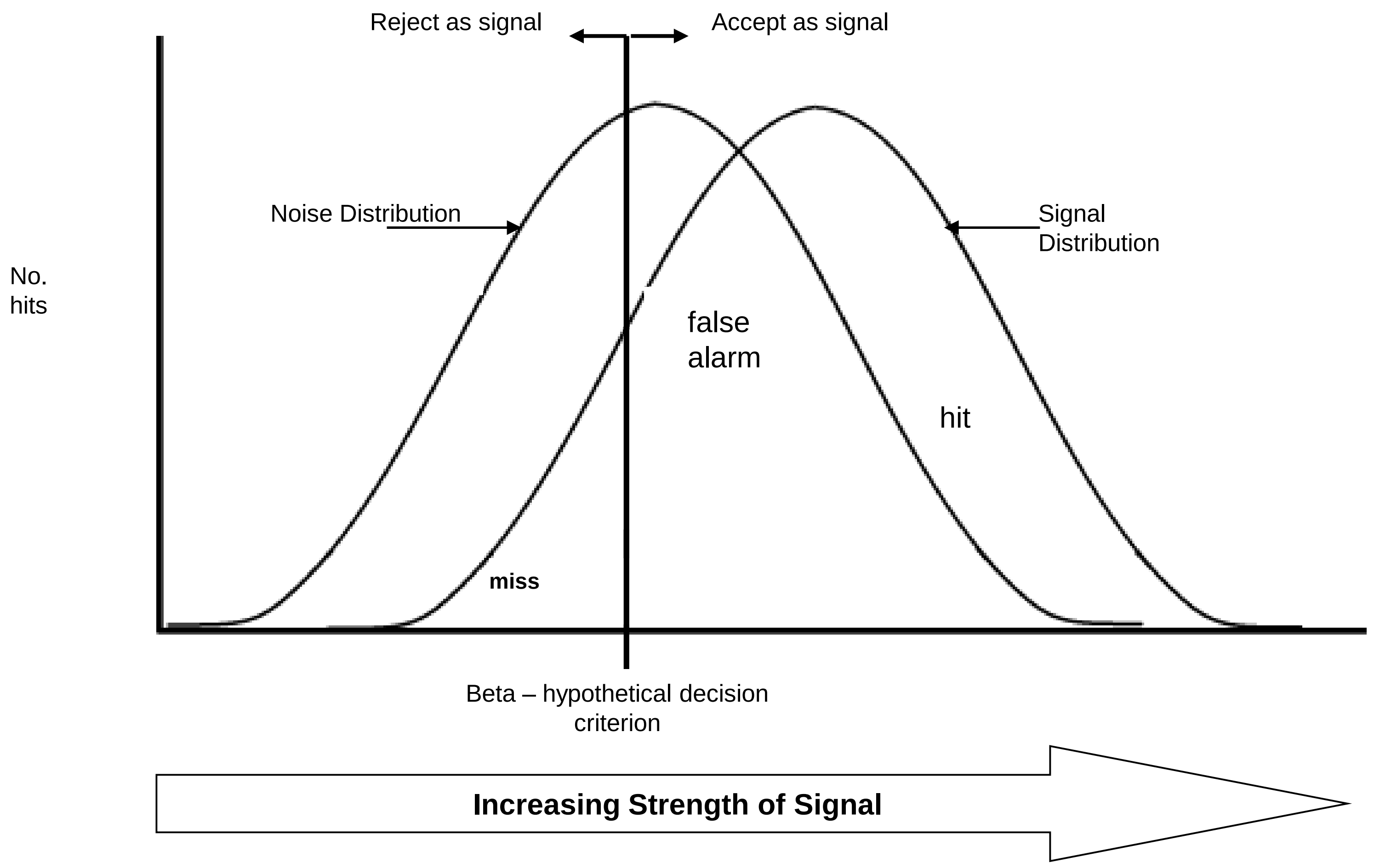
Define ‘Beta’ - some criterion of signal strength above which an inspector will designate a signal as being a ‘hit’

This decision criterion will be a product of

- **Experience**
- **Job instructions**
- **Criticality of the component being inspected**
- **Expectations**
- **Personal biases**

European Aviation Safety Agency

Visual Inspection of Composite Materials
Signal Detection Theory



Visual Inspection of Composite Materials
Signal Detection Theory

Starting point for analysis

Visual Search - entry point for detection of damage

- initiated by a report from crew, e.g. lightning strike, bird strike

- scheduled inspection etc

Visual Inspection of Composite Materials
Signal Detection Theory

Starting point for analysis – influencing factors

- often completed in limited environment, distance, lighting, equipment

- inspectors need to know which panels are composite - what is interpreted as ‘noise’ on what is (incorrectly) thought to be an alloy structure may actually be a missed signal if it is on a composite structure - problem for derivatives and modifications

- some inspectors don’t believe that they will see damage on composite structures (from survey part of study)

- these factors affect the position of ‘beta’, the decision criterion

Visual Inspection of Composite Materials
Signal Detection Theory

Decision Making - follow up

It is assumed that as a product of the visual search further investigation is required. This is done by:

Changing the visual distance, angle, lighting, cleanliness etc

Tactile tests
- tap test
- scratch test
- poke test

Internal Inspection

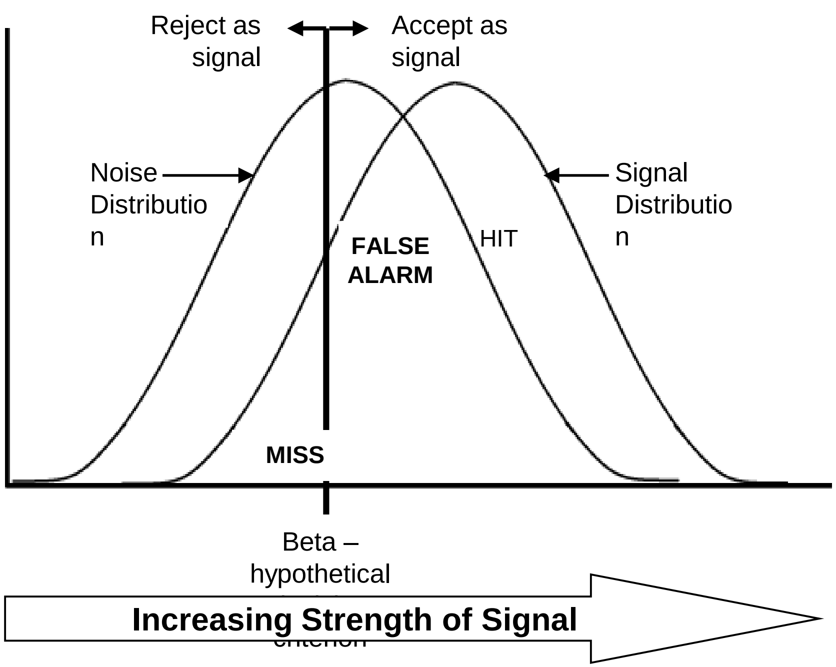
Visual Inspection of Composite Materials
Signal Detection Theory (re-visited)

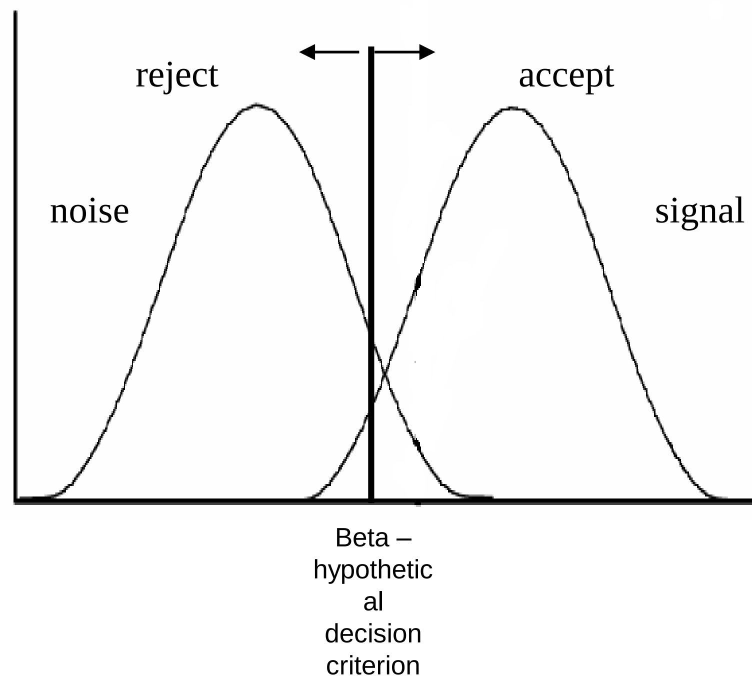
Tests subsequent to the initial visual search are essentially forms of <u>signal conditioning</u>

Subsequent inspection/tactile tests:

- **strengthen the 'signal' (damage) component**
- **filtering the 'noise' component**

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





Tactile Test moves noise towards reject

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

Signal Detection Theory could:

- provide a tool to help us quantify and understand the elements that define the visual inspection, and follow up, processes – a step towards understanding and managing Cat.5
- form part of an inspector training course

Visual Inspection of Composite Materials

issues that may be important: Colour/Finish

How important is Colour/Finish to damage detection?

Although BVID, and associated damage, may not be a DT design driver because it can be captured by larger damages through the damage no-growth design philosophy, the uncertainty regarding a Cat.5 impactor geometry, energy level, or in flight load levels, etc requires that we minimise the chances of missing damage - a BVID indication could flag significant damage. Therefore, understanding the importance of colour/finish at the BVID level could be beneficial (recognising that we do not need no fault founds)

Visual Inspection of Composite Materials

issues that may be important: Colour/Finish

How important is Colour/Finish to damage detection?

Example: Not necessarily just a composites issue:

BA B747 Lap Joint 'Pillowing' (aging aircraft issue 1992) –

Visual inspection for 'pillowing' required, i.e. evident as surface irregularities due to corrosion pressure between the Lap Joint surfaces. If found, this was to be followed by NDT:

New gloss BA Blue - reflection, initially excessive indications of defects, time spent completing unnecessary NDT, some joints even opened due to uncertainty, many 'no fault founds' (subsequent 'cry wolf' – no reaction to 'indications' – what was missed?)

Old Matt BA Blue – few visual indications – what was missed?

Visual Inspection of Composite Materials

issues that may be important: Colour/Finish

How important is Colour/Finish to damage detection?

- preliminary UK OEM ‘quick and dirty’ research indicates an issue, green v white – pylon primary composite structure*

  easier to find damage on green surface than white surface

  easier to find damage on matt white surface than gloss white**

- no consistent OEM approach to colour/finish wrt DT assumptions

- How important is colour/finish for the detection of Cat.5 damage?
- Can we define a new BVID metric for Cat.5 – pulled fastener, creased skin at frame etc – rather than spherical impact dent?

  This needs further research!

*(B-basis calc – Visual Inspection - 1mm deep defects at 2.15m/ 5 secs viewing time – range of lighting and cleanliness investigated)

** disagrees with some other large OEM data

Visual Inspection of Composite Materials

issues that may be important: Preload/Damage

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

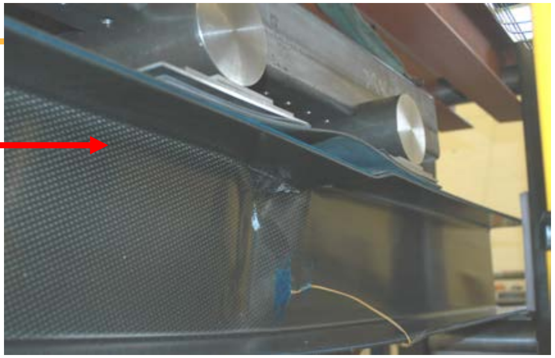
Recognising that real structure is often impacted under load, and that the showing of compliance for metallic structure is usually accepted without load for bird strike, e.g. CS 25.631 – 4lb bird at Vc, a preliminary study* was originally completed to establish if the relatively brittle behaviour of composite material, wrt to metallic structure, would significantly change the behaviour of a structure when subjected to impact such that a significantly different level of safety was being accepted for composite structure.

Note: If we do not have a specific composite requirement to cover an issue, then the assumption must be that a composite structure should be shown to match, or better, the behaviour of an equivalent metallic structure.

* Details available from UK CAA Report CU/WA9/W30814E/62 and Cranfield University (contact Prof. Irving – p.e.irving@cranfield.ac.uk)

Visual Inspection of Composite Materials

issues that may be important: Preload/Damage



Bird Strike of carbon composite ‘C’ section structure, both unloaded and preloaded, impacted with 0.25kg birds at 70-80 m/s indicated:

Damage area produced by impact was reduced by preload

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

Conclusion: Both the ability to detect damage and the residual strength were reduced by preload.

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

Visual Inspection of Composite Materials

issues that may be important: Internal Structure

Is a large dropped tool/dropped container more significant in a composite structure, e.g. cargo floor, and can the damage be found?

Although an impacted internal skin surface may have the benefit that reverse side, i.e. external skin, damage may be visible, there is a potential problem – more complex internal structure (which is often black)

Are we accounting for this adequately – Cat.5?

This needs further research!

Visual Inspection of Composite Materials issues that may be important: Secondary Bonding

Recognising that even NDT is not considered adequate to find a weak bond or tight disbond, e.g. ref. FAR/CS23.573, what are the implications for Cat.5 damage in primary structures with extensive secondary bonding? (e.g. multi-stringer skin – what is the risk of a single batch process error? Would a multi-batch, multi-cure approach be more risky?)

This needs further research!

Visual Inspection of Composite Materials
Conclusion

Safety Message:

1/ Cat.5 damage could be difficult to detect and is potentially very significant. Operators must work on developing a sensible 'blame free culture' such that all and any events are reported – not a new message, but worth repeating.

2/ Inspector training should include an adequate Human Factors element such that all inspectors are aware of the issues that influence visual damage detection and follow-up action, e.g. bias etc.

3/ We need to minimise risk of missing Cat.5 - Is BVID a useful metric for the detection of Cat.5 damage? If so, then we need to understanding the visual damage detection variables, e.g. cleanliness, colour, finish etc and processes. If not, then we need to define some appropriate metrics and/or alternatives - This needs further research!

Visual Inspection of Composite Materials
Conclusion

Safety Message:

4/ Other concerns:

Preload/Damage: Does a preload significantly reduce our ability to detect damage?

Internal Structure: What are the issues regarding the detection of, and significance of, damage to internal composite structure?

Secondary Bonding: What are the issues regarding the detection of Cat.5 damage in structure with extensive secondary bonding?

These need further research!

VISUAL INSPECTION OF COMPOSITE MATERIALS

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"

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