EUROPEAN AVIATION SAFETY AGENCY
AGENCE EUROPÉENNE DE LA SÉCURITÉ AÉRIENNE
EUROPÄISCHE AGENTUR FUR FLUGSICHERHEIT

"Certification of civil composite structures based on detectable damage thresholds – overview and critical NDT detectability thresholds"




BINDT NDI/SHM Meeting

National Composites Centre

February 2016

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Your safety is our mission.

Composite Certification – Damage Thresholds

Certification of civil composite structures based on detectable damage thresholds – overview and critical NDT detectability thresholds

Presentation includes discussion regarding:

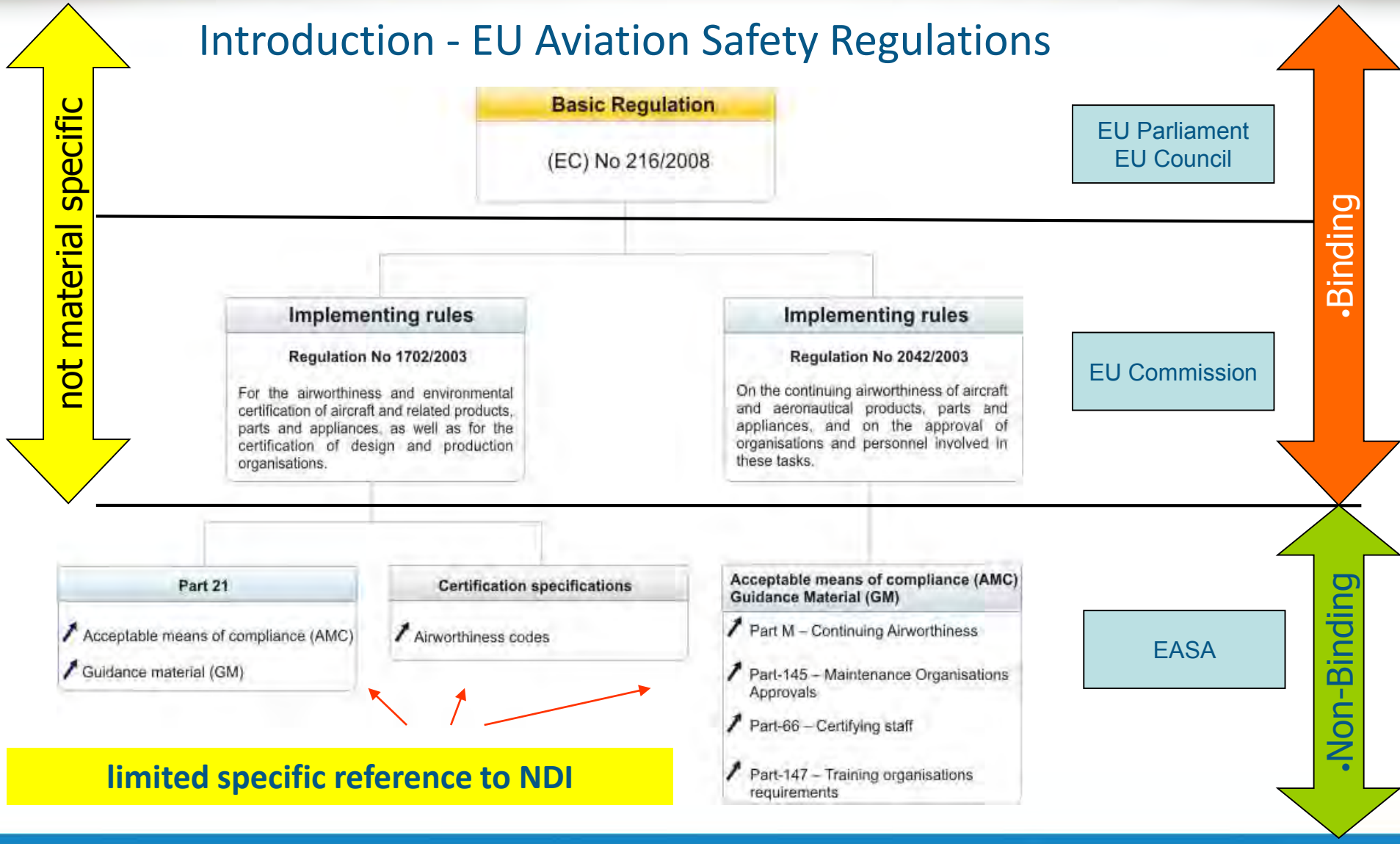
- the regulatory links to damage detection and thresholds
  - Design
  - Production
  - Continued Airworthiness (CAW)
- interpretation with respect to metals and composites (including bonded joints)

Not presented:

- Structural Health Monitoring (SHM)
- Additional support slides

Composite Safety Issues

Introduction - EU Aviation Safety Regulations



Composite Certification – Damage Thresholds

BASIC REGULATION (EC) No 216/2008 - Article 5

(c) no aircraft shall be operated, unless…conforms to the type design approved in its type-certificate and that relevant documentation, inspections and tests demonstrate that the aircraft is in condition for safe operation.

Design: PART 21, Sub. J - Design Organisation Approval (DOA)

- no direct reference to NDI or damage thresholds
- limited identification in supporting **Certification Specifications (CSs)**

discussed here

Production: PART 21, Sub.G - Production Organisation Approval (POA):

- no direct reference to NDI or damage thresholds
- **GM 21.A.147(a)** Qual System changes must ensure no **non-conformity**

e.g. certifiable inspection step

Composite Certification – Damage Thresholds

Maintenance: PART 145, Maintenance Organisation Approval (MOA):

- limited reference to NDI
- **PART 145.A.30(f), AMC 145.A.30(f)** Personnel requirements

2. Appropriately qualified means to Level 1, 2 or 3 …EN 4179 dependant upon the non-destructive testing function to be carried out.

5. Particular NDI means; Dye penetrant, magnetic particle, eddy current, ultrasonic and radiographic methods including X ray and gamma ray

6. …new methods …not limited to thermography and shearography, …not specifically addressed by EN 4179. Until such time as an agreed standard is established such methods should be carried out iaw particular equipment manufacturers recommendations* including any training and examination process to ensure competence of the personnel with the process.

*** iaw TCH acceptance and specifications**

Conclusion:

- limited direct reference to damage thresholds or NDI in requirements

Composite Certification – Damage Thresholds

changing to Environmental Damage (ED)

Certification Specifications CS25: Large Aeroplanes:

CS25.571: ***Damage-tolerance & fatigue evaluation of structure***

'(a) General. An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, or accidental damage (AD), will be avoided throughout the operational life of the aeroplane…' *(also see MSG3, e.g. para. 2.4.3)*

Current Situation: Metal threat - Fatigue and ED (corrosion)

Composite threat - AD and ED

- significant extended application of composites, particularly in structures likely to be subject to impact, e.g. fuselage
- limited in-service experience with these materials in these extended application

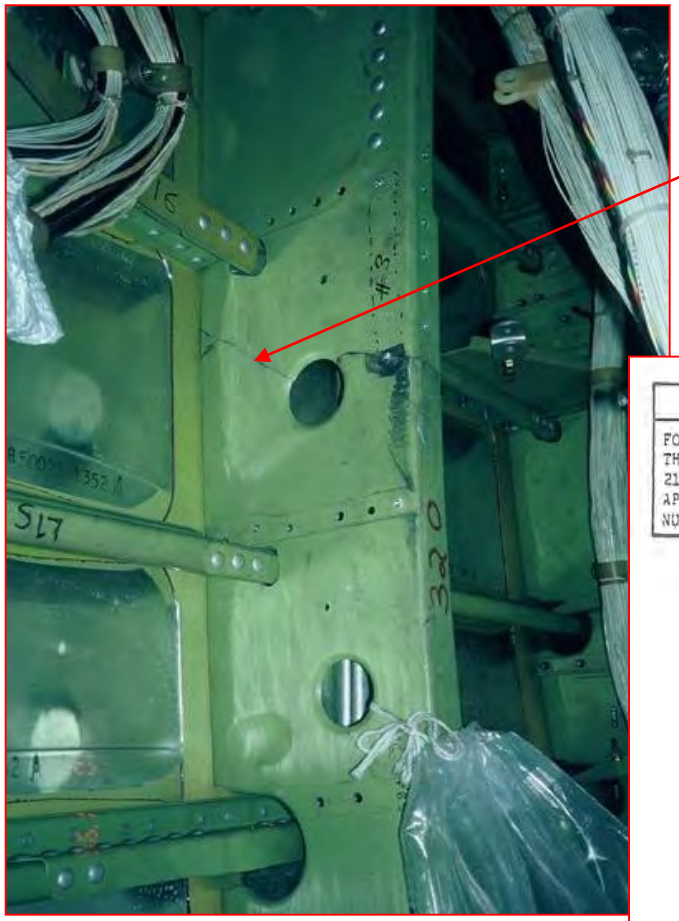
TC acceptance based upon:

- extensive test, analysis supported by test
- robust design strategy

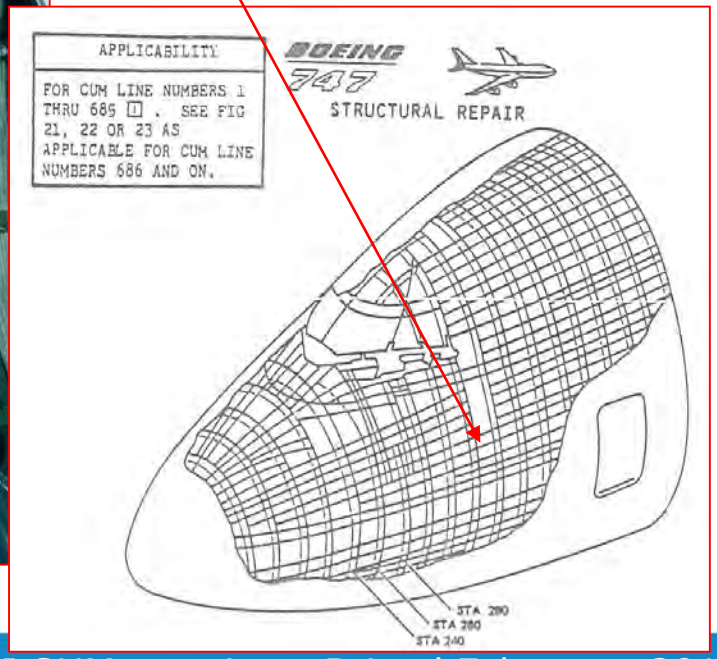
25.571 building block for ageing aircraft issues AMC 20-20

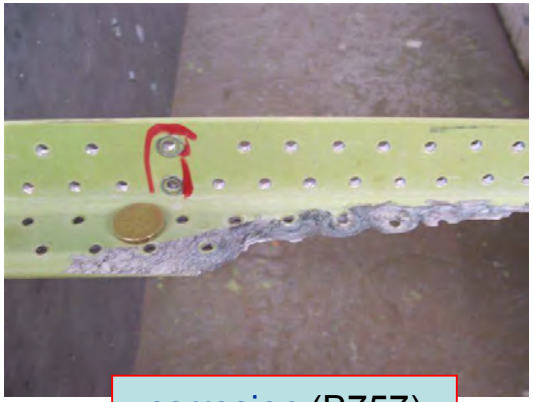
metals

Metallic structure usually offers a surface damage indication –



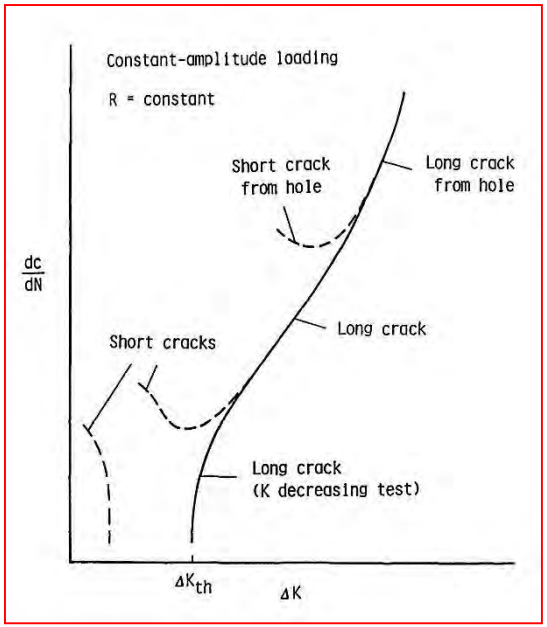
fatigue crack BS320 Str.17

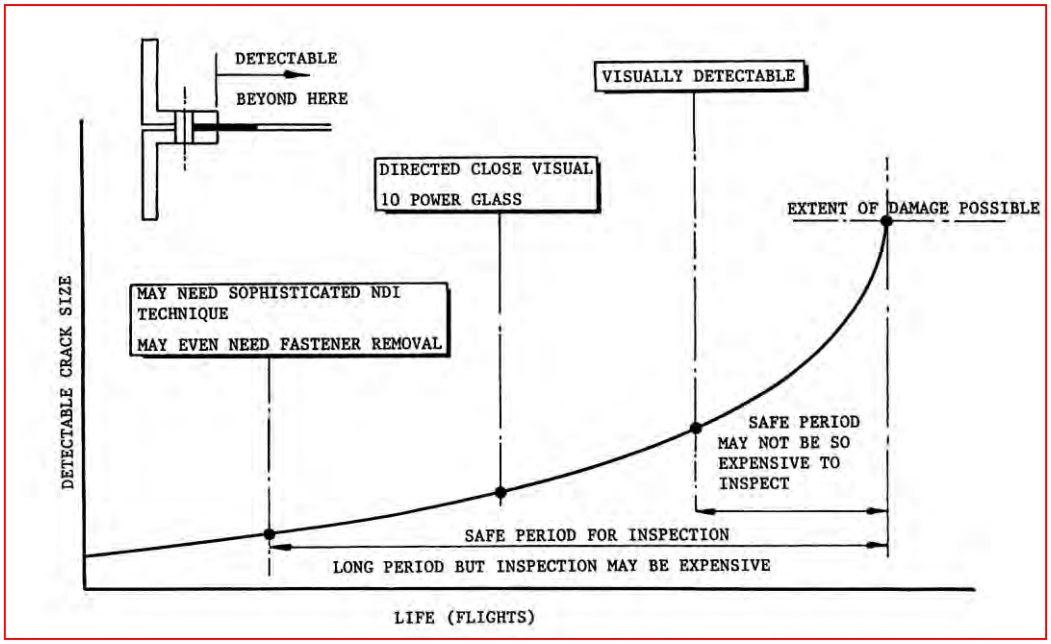




corrosion (B757)

Damage – Inspection and Damage Tolerance:





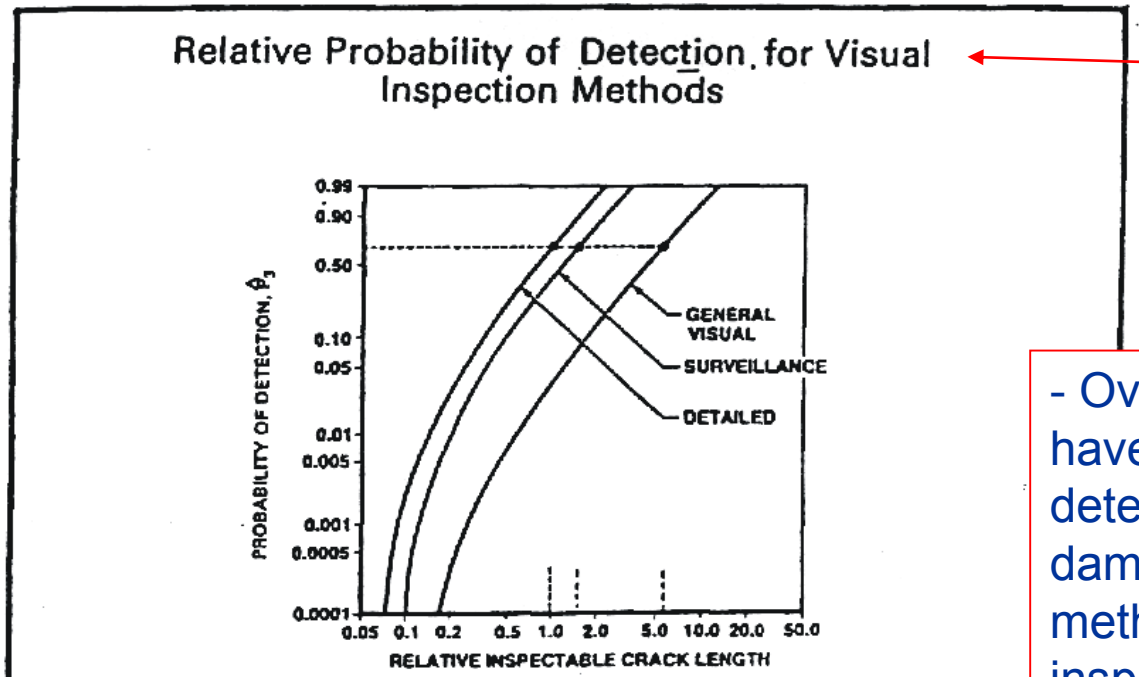
Metallic structure: Typically,

For most airframe: crack growth (da/dN) vs stress intensity factor is **understood** (empirically), damage detectable **– damage tolerance** - maintenance schedule (MS) credit

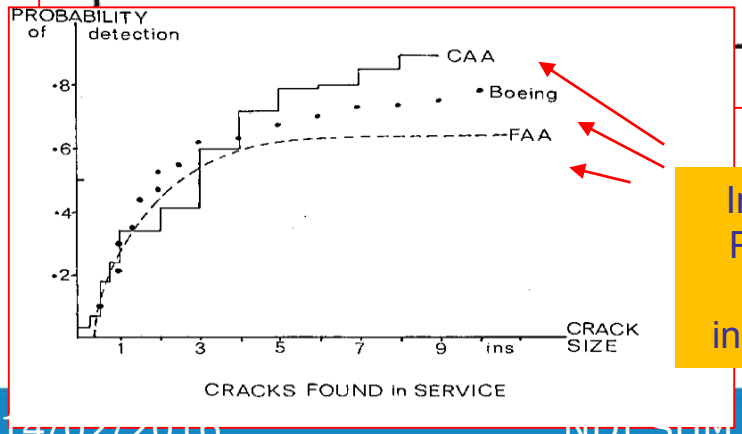
For undercarriage, engines: crack growth (da/dN) vs stress intensity factor too steep, damage not readily detectable **– safe life**

Composite Certification – Damage Thresholds

metals



similar POD data for NDI methods: UT, X-ray
- use for 'equivalence' if changing inspection method/frequency etc



Inspection POD data sources inconsistent

- Over 35,000 service events have been evaluated to determine probability of visual damage detection for different methods and types of inspection.

- the crack length detectable in a general visual inspection is six times greater than for a detailed visual inspection.

metals

Damage – Inspection and Damage Tolerance:

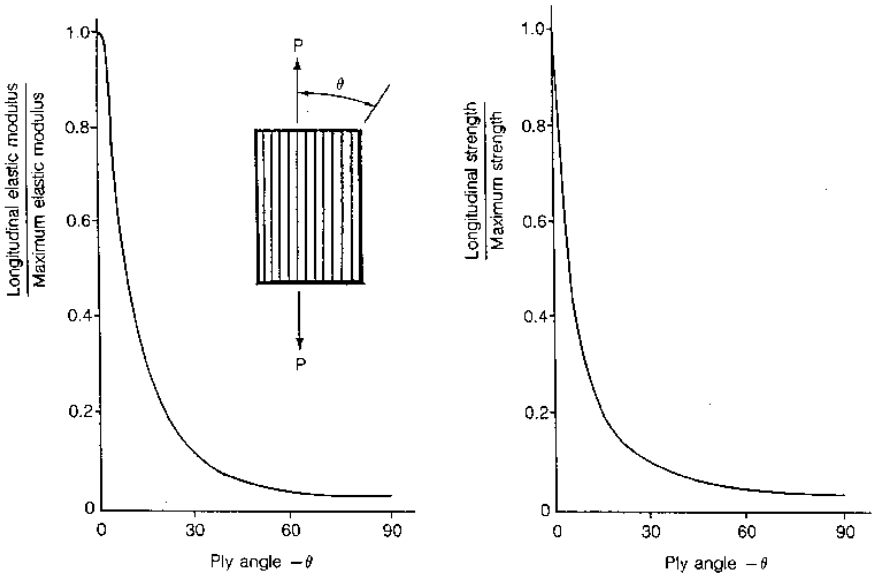
Safe Life
(including flaw tolerance safe life) → necessary due to practical inspection* threshold limits

Damage Tolerance → relies upon inspection* threshold limits and frequency

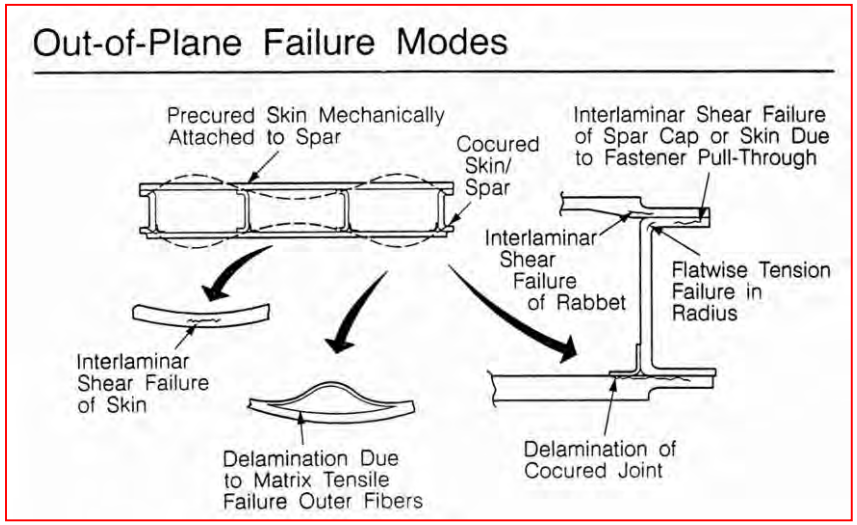
* ‘or other procedures’

What are the potentially significant differences between typical metal and composite engineering properties?

Anisotropy: Significant strength/stiffness reduction with ply orientation relative to load



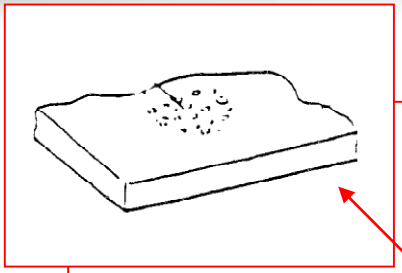
Strength/Stiffness v Ply Angle
(non-dimensionalised)



Anisotropy: potentially difficult to predict:

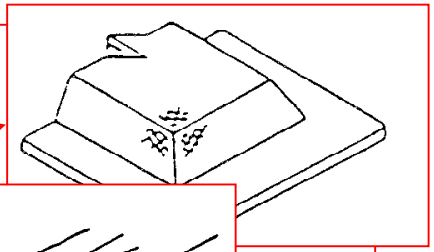
- **failure loads**
- **damage modes**
- **damage locations**

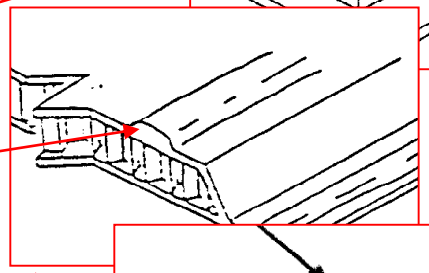
Composite Certification – Damage Thresholds

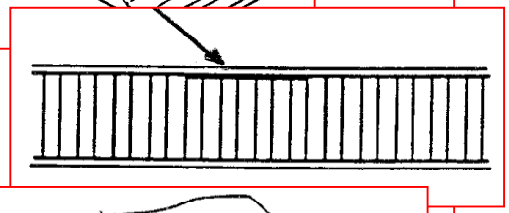


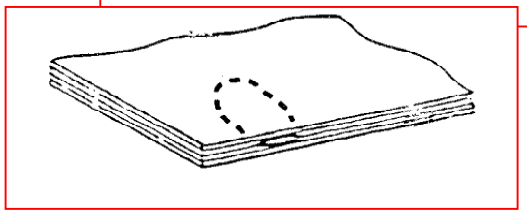
Many Composite defect sources exist in production*…some visible, some not

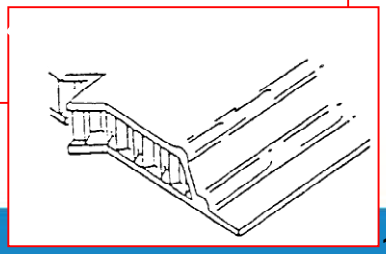
- Porosity/voids
- Resin starved areas
- Resin-rich or fiber-starved areas
- Disbonding or delamination
- Mis-orientation of and missing plies
- Wrinkles and local fiber waviness
- Ply overlaps or gaps
- Contamination/embedded foreign inserts





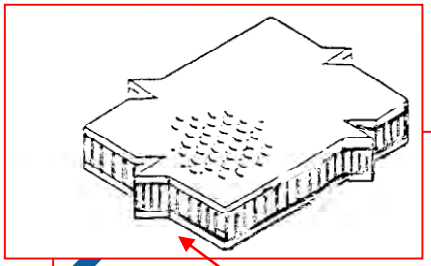






* see CMH-17 V3C13 for more detail

Composite Certification – Damage Thresholds

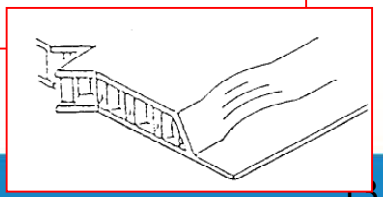


Many defect sources in production…*

Note: Repair is often 'production process' in a service environment (material properties built into part)

- potentially more variable (defects more likely)

- Dimpling
- Fibre Break-out
- Foreign object impact damage
- Improper curing
- Cured part dimensions and warpage out-of-tolerance
- Machining defects at holes, cutouts and edges
- Improper fastener installation
- Scratches, fiber breakage, damage done in handling
- Specification allowances for manufacturing defects



* see CMH-17 V3C13 for more detail

Composite Certification – Damage Thresholds

also consider additional defect sources in service environment e.g.

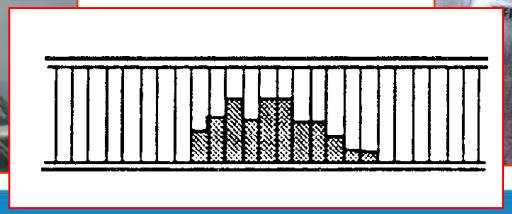
- different impact threats
(high energy blunt impact, overload, hail etc)

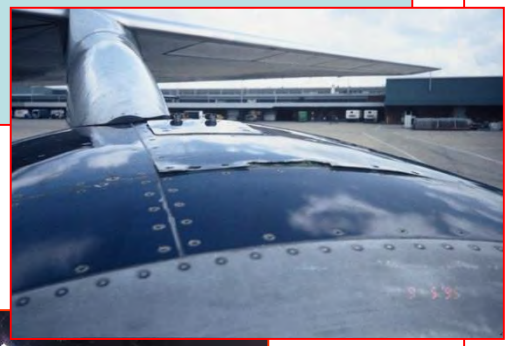
- moisture in parts etc

- heat damage

- erosion

- lightning etc

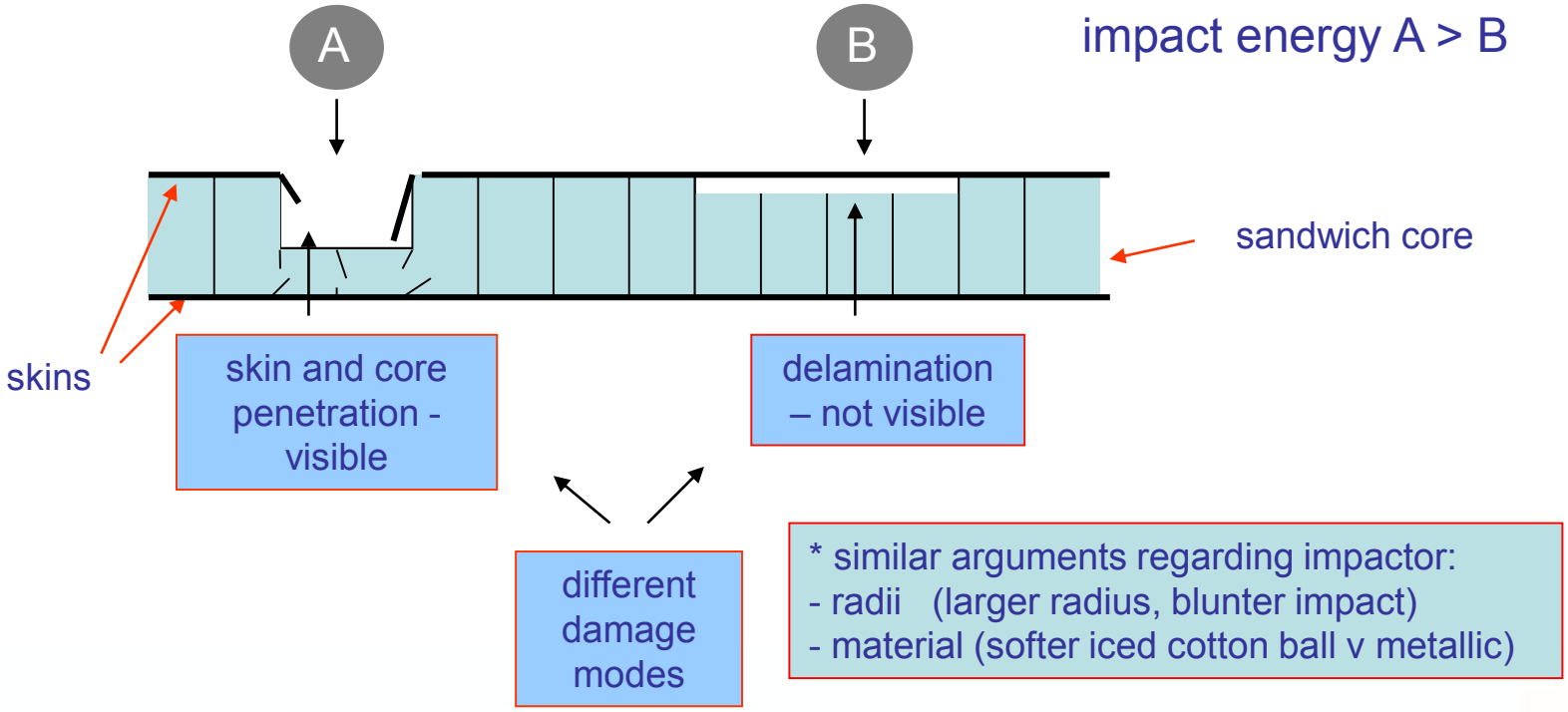




Competing Damage Modes

Example - Hail Damage (thicker skin sandwich structure)

Danger!: common to show no-damage growth with higher impact energy visible damage 'A', when lower impact energy invisible damage 'B' is potentially less conservative*!



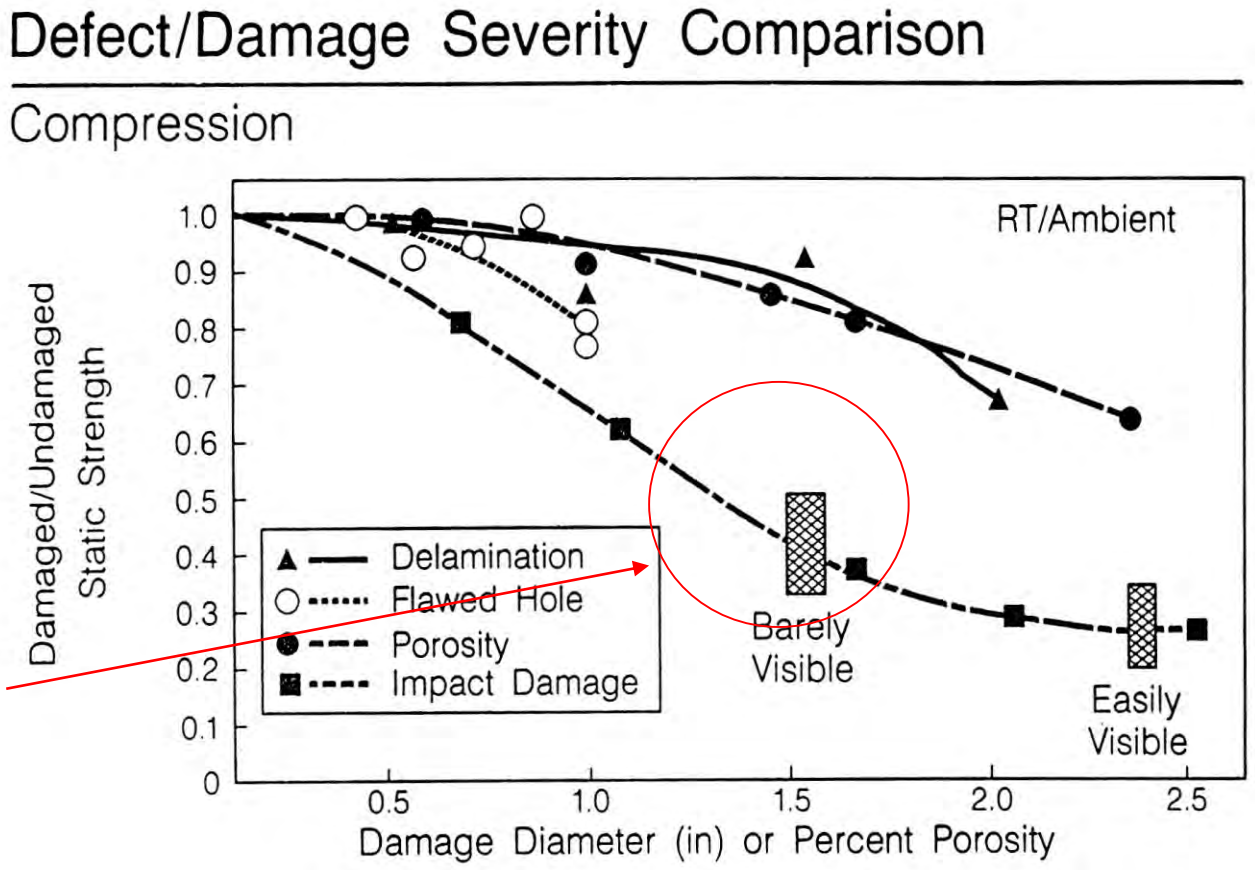
Damage – Inspection and Damage Tolerance: Residual Strength

Anisotropy:

Potential for significant Barely Visible/Non-Visible Damage….

Composites:

- relatively low out of plane, compressive, and shear strength
- impact sensitive
- strength/stiffness reduction for **critical damage modes**
- material relaxation



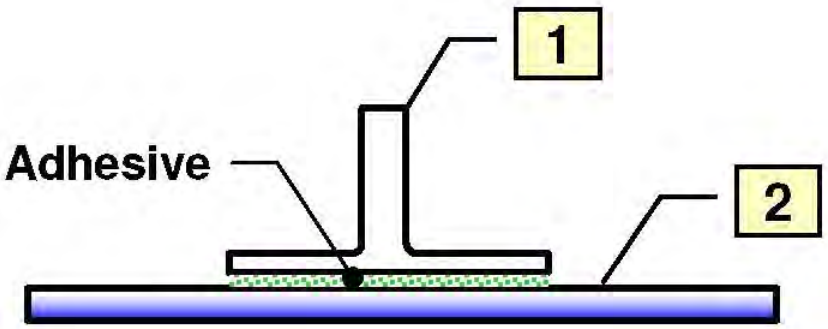
Composite Safety Issues

Bonded Structure
- see support slides

AMC 20-29 Para.6. **MATERIAL AND FABRICATION DEVELOPMENT**

C. STRUCTURAL BONDING

- important existing rule regarding Bonded Structure – 23.573(a)(5)
  - approach used in other specifications, CS25, 27, 29, CS-P etc
    (now broader use formally recognised in AMC 20-29)



Structural Bonding:
- extremely sensitive to process
- particular caution is required if item 1 and/or 2 is pre-cured or metal, requiring:
- surface protection, cleaning, preparation etc

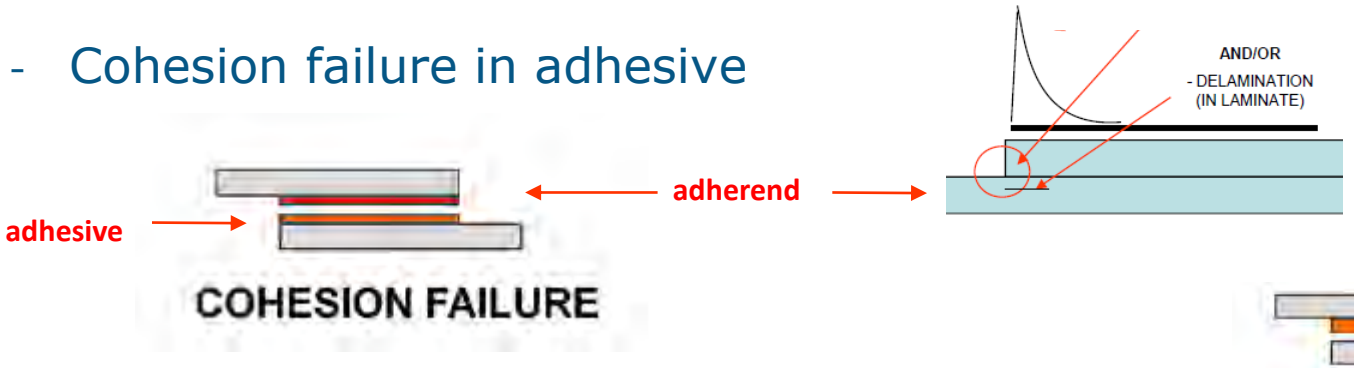
Composite Safety Issues

Bonded Structure
- see support slides

AMC 20-29 Para.6. **MATERIAL AND FABRICATION DEVELOPMENT**
C. STRUCTURAL BONDING

Acceptable failure modes (one dominant repeatable mode preferred):

- Adherend failure (preferred)
- Cohesion failure in adhesive



cannot find
'weak bonds'
Critical structure to
use back-up features
to maintain
Limit Load

- ADHESION FAILURE – UNACCEPTABLE (disbond*)
(at interface between adhesive and adherend)
  - contamination, compatibility etc

*'disbond' and 'debond' used interchangeably in lit.
However, 'disbond' – accidental, 'debond' – intended (access, repair)
Note: See work by Max Davis regarding bonded structure challenges.

Bonded Structure

Composite Safety Issues

Several conditions are required to exist together for disbond or delamination to be a safety issue:

- a disbond/weak bond/delamination exists
  &
- < UL capability
  (large damage/disbond, critical location)
  &
- damage/defect remains undetected
  &
- load event > Residual Strength capability (>LL)

e.g. in-service disbond reported (repair/production issues) approx:
1 incident 10^6 hrs
1 serious incident 10^8 /10^9 hrs
No fatal accidents
(CAA-UK MOR & fleet data only)

- these conditions do occur, but typically not together…..
- not enough data to meaningfully quantify*
- most events not significant safety issue
  (most applications have not been significant)

However, some have
(incidents beyond CAA – UK data)
1 serious incident/accident
>10^8 hrs

* Note: existing data is poor…
– need to improve cause forensics and database taxonomy

Standardisation of Certification Requirements for Composites

23.573(a)(5): *'For any bonded joint, the failure of which would result in catastrophic loss of the aeroplane, the **limit load** capacity must be substantiated by one of the following methods:*

*(i) The maximum disbonds of each bonded joint consistent with the capability to withstand the loads in paragraph (a)(3) (i.e. critical limit flight loads considered ultimate) …must be determined by analysis, tests, or both. **Disbonds of each bonded joint greater than this must be prevented by design features;***

Not to be used to address poor process… unacceptable, CS"x.601, 2x.605

or

*(ii) **Proof testing** must be conducted on **each production article** that will apply the **critical limit design load** to each critical bonded joint;*

Not practical for large aircraft, does not address degradation, loading process damage

or

*(iii) **Repeatable and reliable non-destructive inspection techniques** must be established that ensure the strength of each joint.'*

'Weak Bonds' and 'Tight Disbonds'

- *cannot be reliably detected by Visual Inspection*
- *have not been shown to be reliably detected by NDI at a production scale*

Composite Safety Issues

Example: Propellers (importance of back-up feature)

- the intent of CS23.573 (fixed wing < 5700 kg) is used elsewhere, e.g. CS-P (propellers):

CS-P 160: Propeller Critical Parts Integrity

'(a) critical parts to be withdrawn from service at a life before hazardous failure (> 10^{-7} hr) can occur'

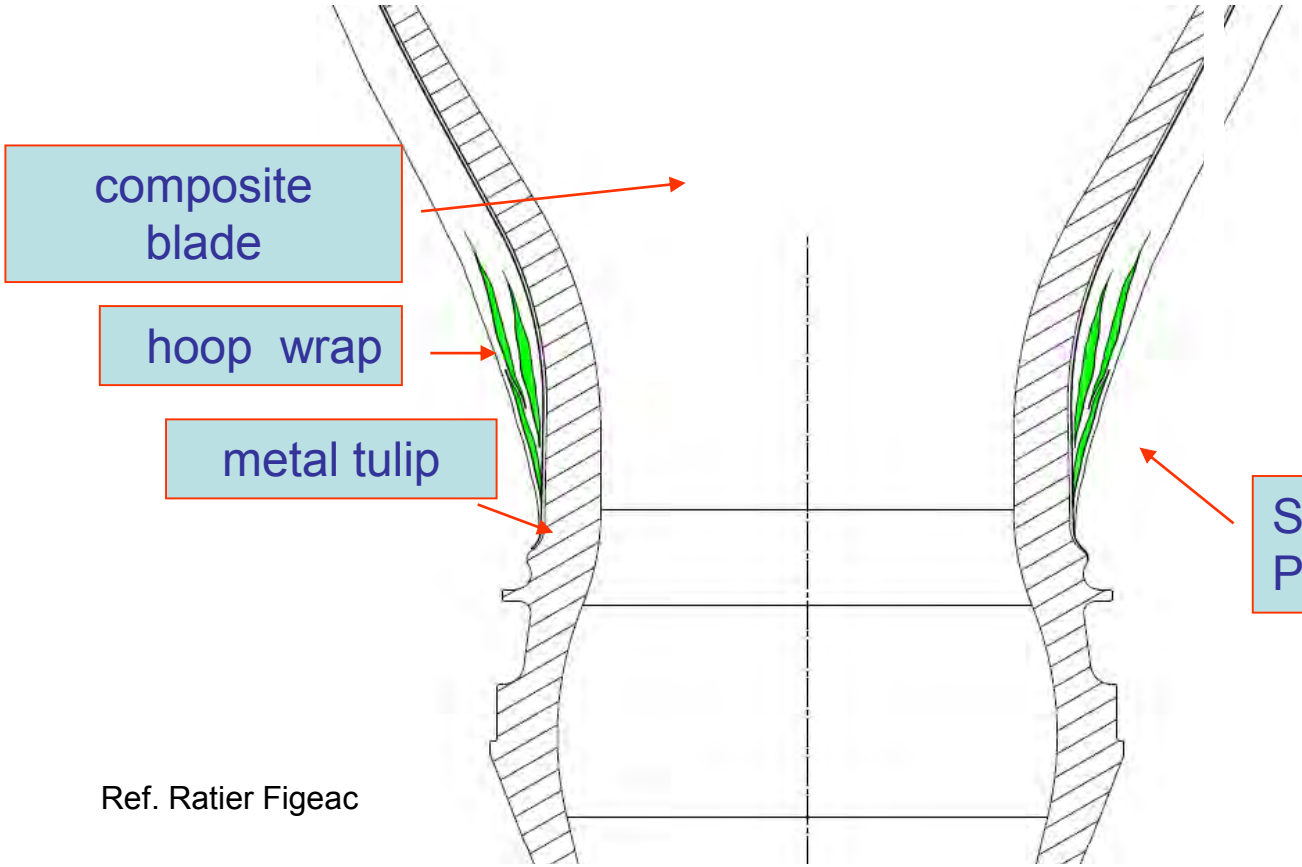
also note

CS-P 150: Safety Analysis Hazardous Propeller effects include..

'(g) (iii) release of the propeller, or any major part of the propeller'

Therefore, because it is difficult to detect, or predict growth (i.e. determine life) of, a disbond, particularly in a complex root structure, then a Fail-Safe feature (a strap) is required to make the propeller airworthy

Composite Safety Issues



Ref. Ratier Figeac

Propeller Fail-Safe Strap

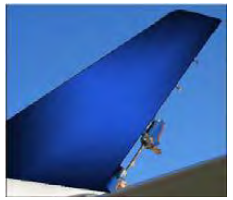
Composite Safety Issues

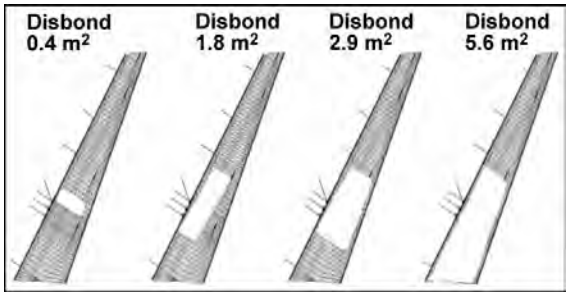
Bonded Structure

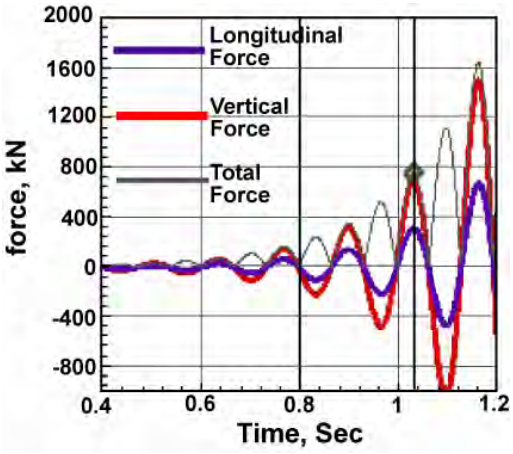
Example: A300 Rudder Loss (and sandwich repair issues):

- extensive Airbus work to understand **Ground-Air-Ground (GAG) cycle**
(Airbus: Roland Thevenin, Ralph Hilgers presentations CMH-17 26-28/9/11 Delft)

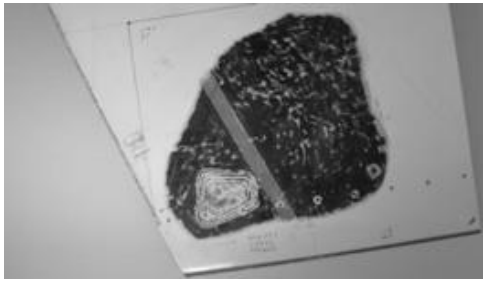
- CMH-17 Disbond/Delamination Working Group* Activity
(Airbus: NASA: Ronald Krueger)

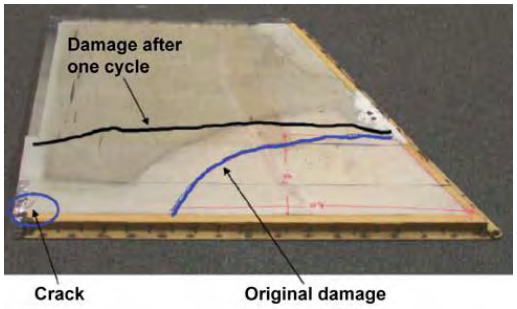






Load response – from time domain flutter analysis





typical existing fleet structure configurations

* plan to extend WG activity to include non-pressure cycle related GAG issues, monolithic structural bonding etc

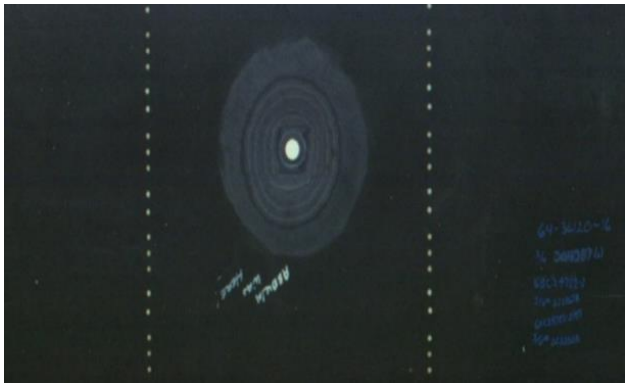
Composite Certification – Damage Thresholds

EASA Certification Memorandum (Harmonised FAA):

Bonded Repair Size Limits*

CM No.: CM-S-005 Issue 01 issued 11 September 2015

- captures intent of CS23.573(a)5, applied to in-service repairs
- more challenging environment than production

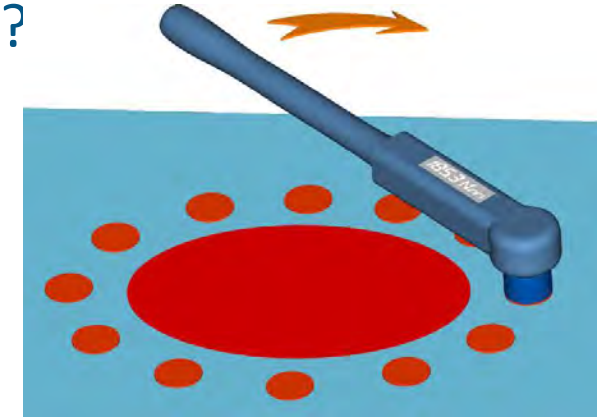


*http://easa.europa.eu/system/files/dfu/'final'%20CM-S-005%20Issue%2001_Bonded%20Repair%20Size%20Limits_PUBL.pdf

Composite Safety Issues

AOB: Developing Ageing A/C Repair work

Alan Baker Papers: Value of Witness Patches?



Although not representative of actual repair, e.g.

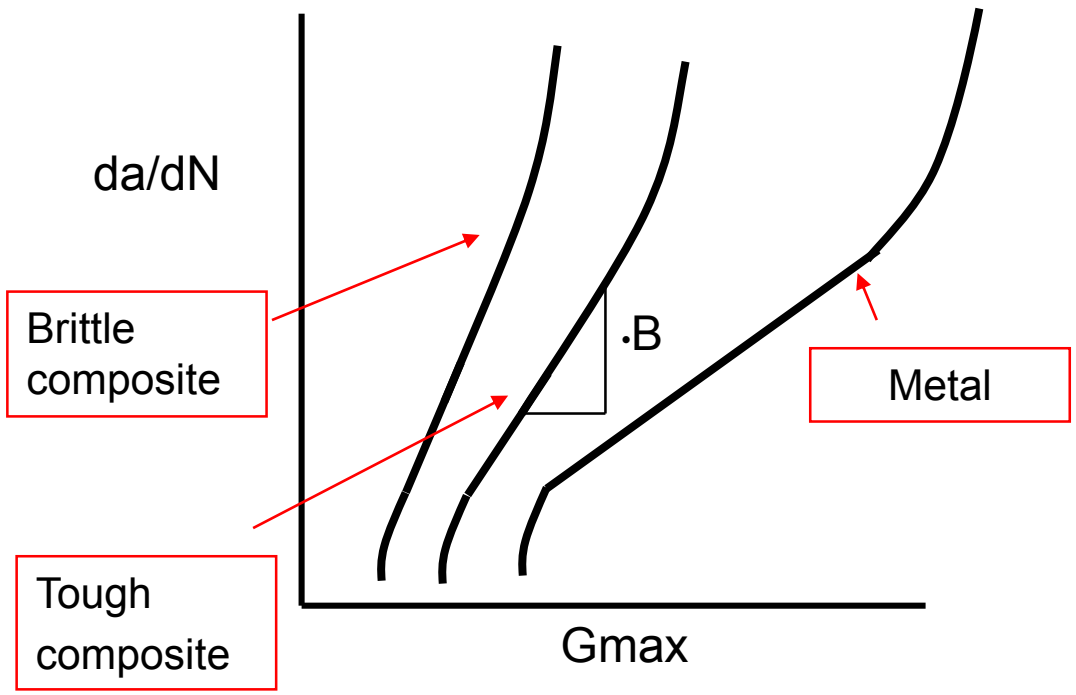
- thickness of bond
- pressure at repair bondline interface
- cure heat condition
- working stress levels etc

Could witness patches provide a conservative indication of bond degradation (being more exposed to environment than actual repair bond line)?

- work in progress

scheduled removal to assess bond degradation?

Damage – Inspection and Damage Tolerance:



$$\frac{da}{dN} = AG^B \qquad G \propto P^2$$

$$\Rightarrow \frac{da}{dN} \propto P^{2B}$$

Material	B
Steel	1.6
Aluminium	2.2
Carbon/Thermoplastic	6.1
Carbon/Epoxy	12.2

- Solution :- ensure that when damage is present, G is below a threshold value for crack growth

Composite structure: Typically, **crack growth (da/dN) not understood, some damages not detectable – mixed/competing damage modes. No-Growth philosophy necessary to comply** – substantiated damage threat survey necessary in MS development

Damage – Inspection and Damage Tolerance:

No-growth** → necessary due to inspection* threshold limits

Slow growth
Arrested growth** → relies upon inspection* threshold limits and frequency

** relies upon
- damage threat survey
- substantiation in test/analysis pyramid

* 'or other procedures'

Composite Certification – Damage Thresholds

Existing CS25 Structures Regulations of particular interest and potential relevance include:

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'

Does not need to be visual, Note: 80-90% of inspections are visual

Does not need to be an 'inspection'

Notes:

1/ EASA does not approve inspection standards, but accepts them as part of a process, project etc - provided that they are shown to be validated, applicable, and repeatable

2/ technology and technology application changes must not reduce the existing 'acceptable level of safety'

Composite Certification – Damage Thresholds

Existing CS25 Structures Regulations of particular interest and potential relevance include:

CS 25.1529 – Appendix H: Instructions for Continued Airworthiness:

'H25.3 (b) maintenance instructions

'an inspection programme that includes the frequency and extent of the inspections necessary to provide for the continued airworthiness of the aeroplane must be included.'

H25.4 (a) Airworthiness Limitations section

'(1) Each mandatory replacement time, structural inspection interval, and related structural inspection procedure approved under CS 25.571…'

Composite Certification – Damage Thresholds

Existing CS25 Structures Regulations of particular interest and potential relevance include:

AMC 20-29 para.8(a)(3) for composites.

account for potential competing damage modes

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

colour, surface, finish?

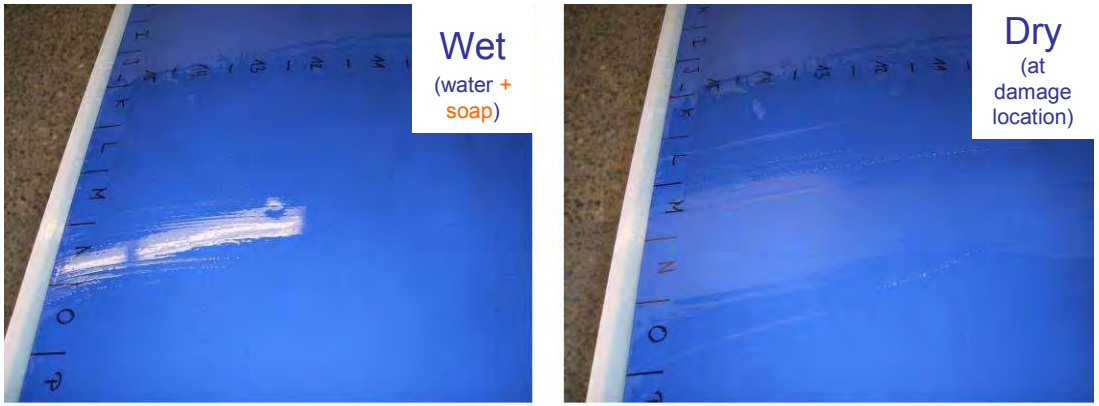
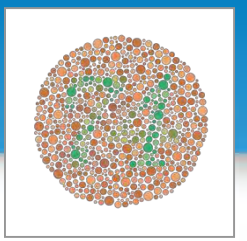


Figure 60: Surface wetting, to improve detectability of dents on matt surface.

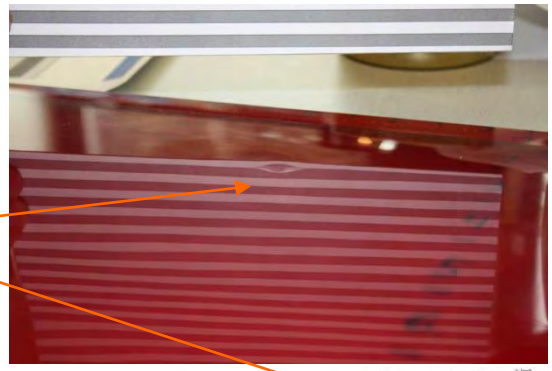
Composite Certification – Damage Thresholds

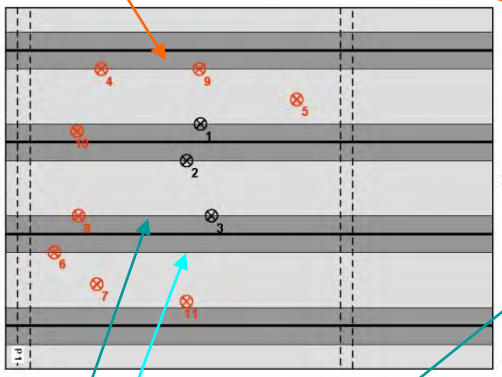


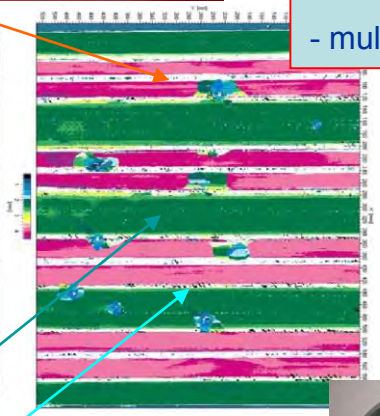
Φ 25.4 mm

impact 9 - 60J

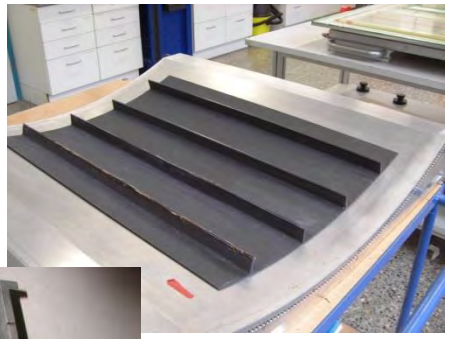
damage visible
(enhanced for photo)

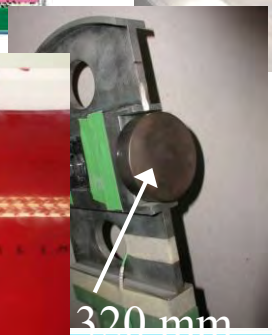


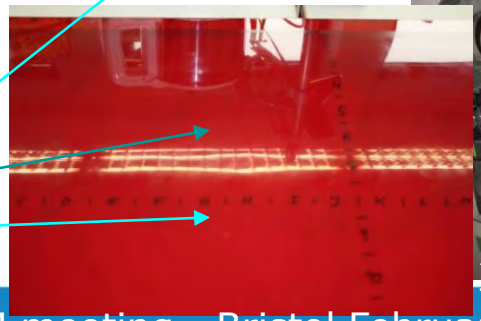




- larger impactors (more realistic threat?)
- representative structure
- damage at reasonable energy levels
- damage not visible (>Allowable Damage Limits?)
- multiple impacts?







Φ 320mm

impact 2 - 60J,
impact 3 - 75J

damage not visible

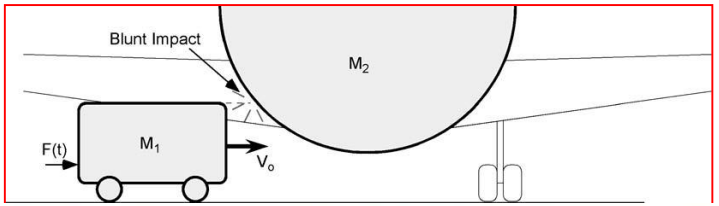
320 mm

Visible Damage
Blunt Impact

Composite Certification – Damage Thresholds

High Energy Wide Area Blunt Impact (HEWABI):

Potentially significant damage **not** externally Visible*
(contact area highlighted)



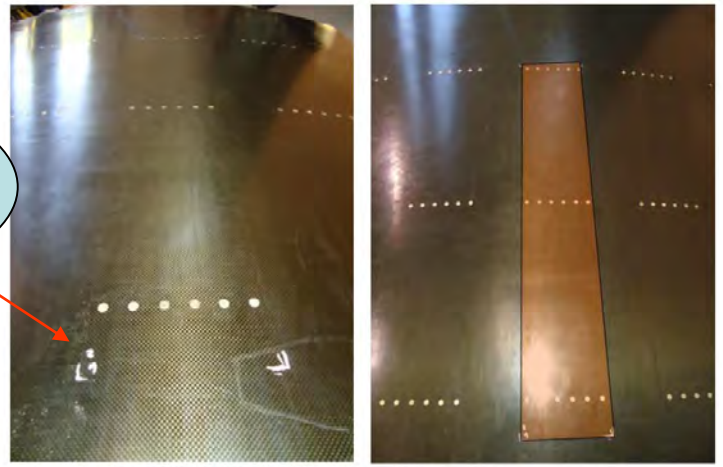
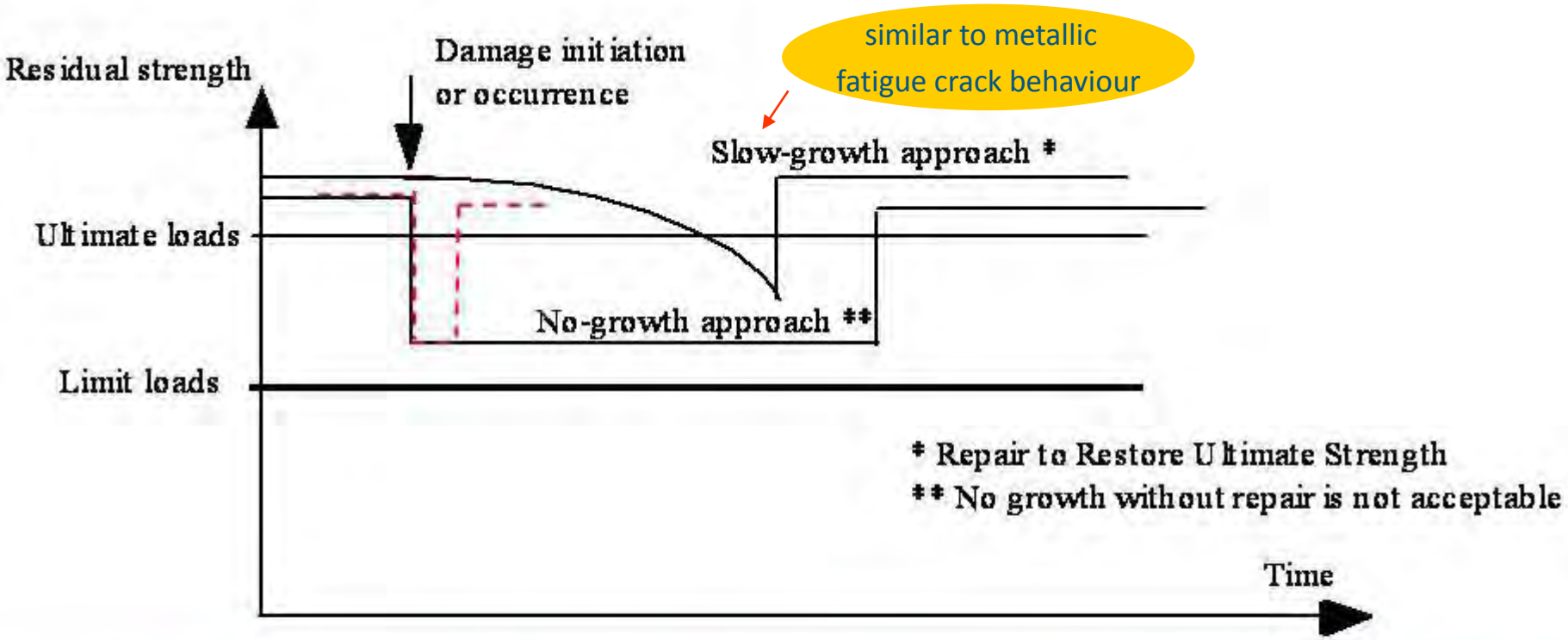


Figure 76. Outer skin surface after testing showing the load application region

30-40% damage
- ground impact

*Internal damage – address appropriately as Cat 2, using substantiated damage threat survey and inspection schedule.
Note: Cat 5 is outside certification and should be obvious and immediately reported (see developing Policy)
Note: Any significant event or visible damage should be investigated and supported by NDI, e.g. Ramp Damage Checker

Composite Certification – Damage Thresholds



AMC 20-29 Figure 4 - Schematic diagram of residual strength illustrating that significant **accidental damage** with "no-growth" should not be left in the structure without repair for a long time.

Composite Certification – Damage Thresholds

Composite Design Philosophy:

Do not reduce existing 'Acceptable' Level of Safety

- Result of: experience, R&D, 'engineering judgement', reaction to incidents and accidents, and regulations existing at the time of certification, Type Certificate Holder in-house design practice
- show 'equivalence' to metallic structure

Robust structural level design concept

- address all identified certification threats
- similar to metallic structure, e.g. T. Swift philosophy
  - local damage may be different, but structural level failure may be driven by the similar failure mode, e.g. buckling

Composite Design Philosophy: Robust design concept
– Large Damage Capability (LDC)

- similar to metals except:
  - more competing damage modes,
    e.g. large notch, disbond, delamination etc
  - some damage modes not so readily detected

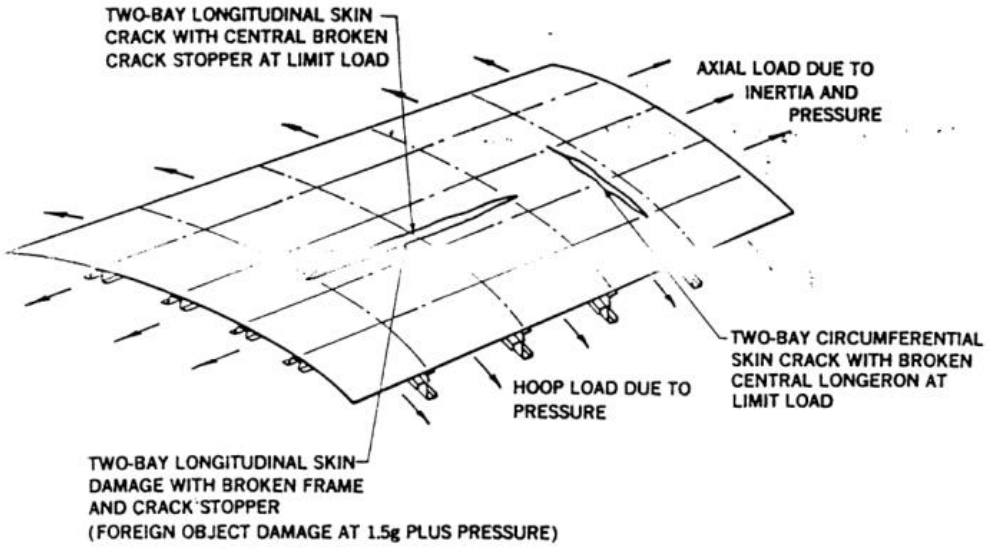
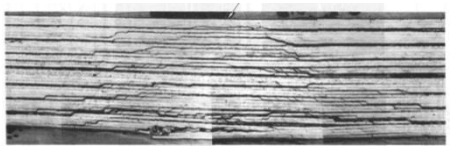


FIGURE 2. FUSELAGE DAMAGE TOLERANCE SIZES FOR STRUCTURAL DESIGN

Metal Design - Design for Redundant Structures' - T. Swift

Composite Certification – Damage Thresholds

AMC 20-29 Para.8. **PROOF OF STRUCTURE - FATIGUE AND DAMAGE TOLERANCE**



Category 1 Damage:
BVID, Allowed Mfg. damage

Category 2 Damage:
VID, damage requiring repair per normal inspection process

Category 3 Damage:
Obvious damage found within a few flights of occurrence, requiring immediate repair

Category 4 Damage:
Discrete source damage, obvious to flight crew, requiring repair after flight

Category 5 Damage:
Anomalous damage not covered in design but known to operations, requiring immediate repair

Design Load Level

Ultimate

1.5 Factor of Safety

Limit

~ Maximum load per lifetime

Continued safe flight

Allowable Damage Limit (ADL)

Critical Damage Threshold (CDT)

Increasing Damage Severity

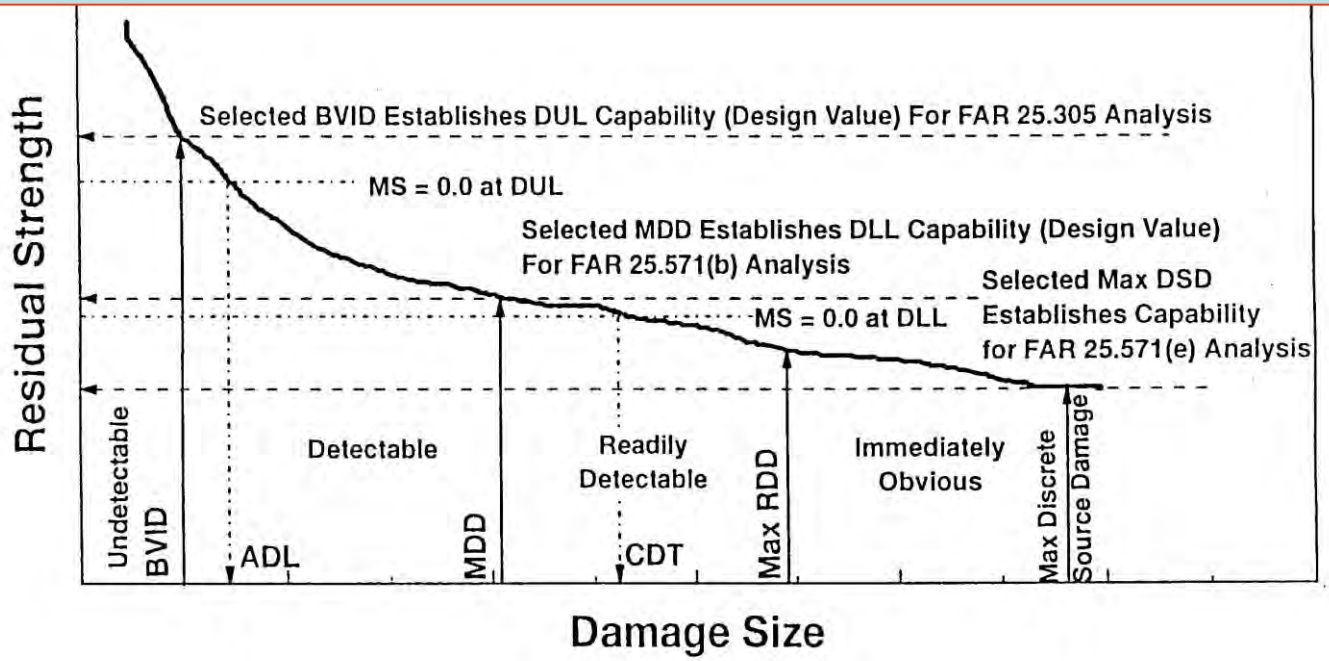
Notes:
1/ Cat 3 Ξ JAA 50 cycle detection
2/ Cat 5 – outside certification
3/ 'deterministic' and 'semi-probabilistic' approaches possible – see support slides

Design Load Levels versus Categories of Damage Severity

Composite Certification – Damage Thresholds

Residual Strength Requirements versus Additional Damage Size

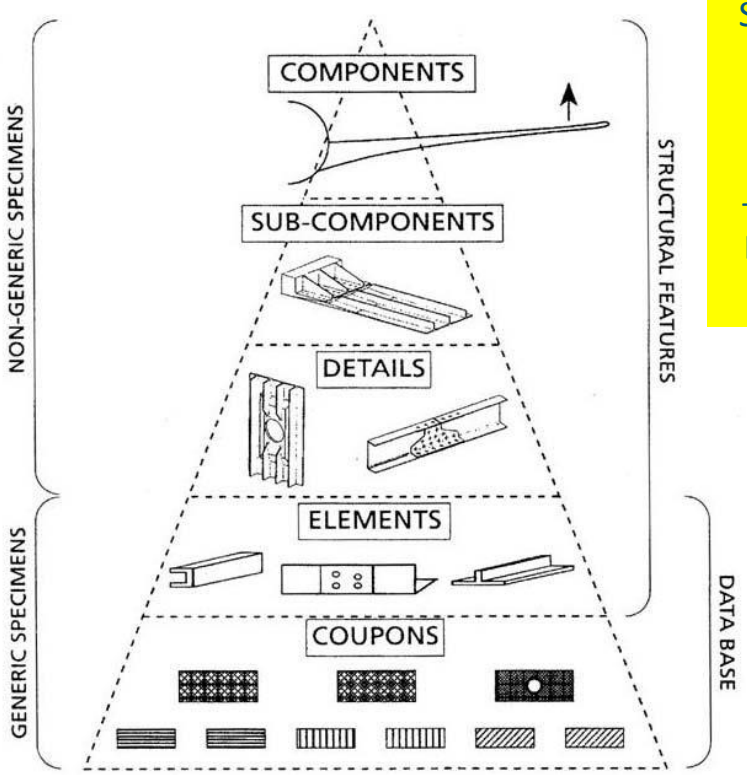
(from CMH-17 Fig. 12.2.2.3(a))



BVID: Barely visible impact damage
DUL: Design ulimate load
MDD: Maximum design damage
ADL: Allowable damage limit
CDT: Critical damage thershold

DLL: Design limit load
DSD: Discrete source damage
RDD: Readily detectable damage
MS: Margin of safety

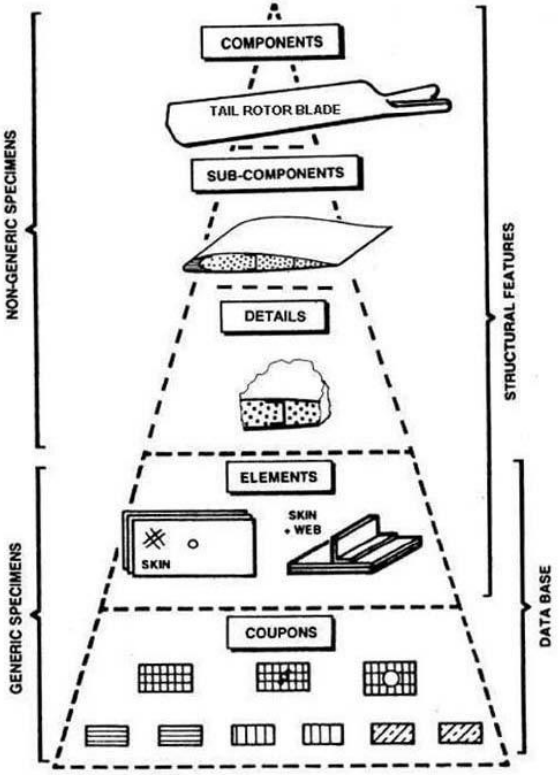
Substantiation: Test/Analysis Pyramid (Building Block)



AMC 20-29 Figure 1 - Schematic diagram of building block tests for a fixed wing.

Static and F&DT damages substantiated in mid-upper test/analysis pyramid

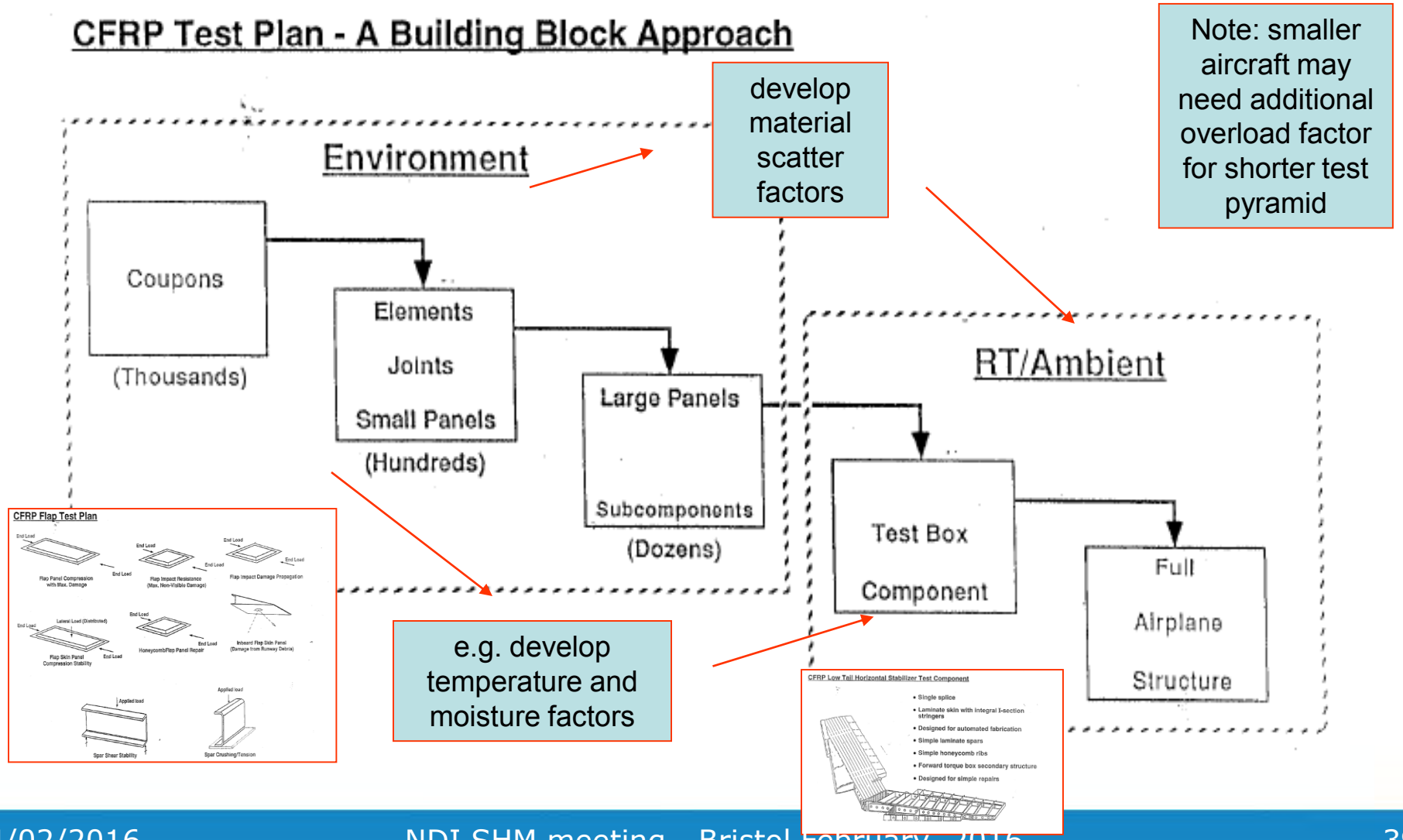
- typically, representative Boundary Conditions are essential



AMC 20-29 Figure 2 - Schematic diagram of building block tests for a tail rotor blade

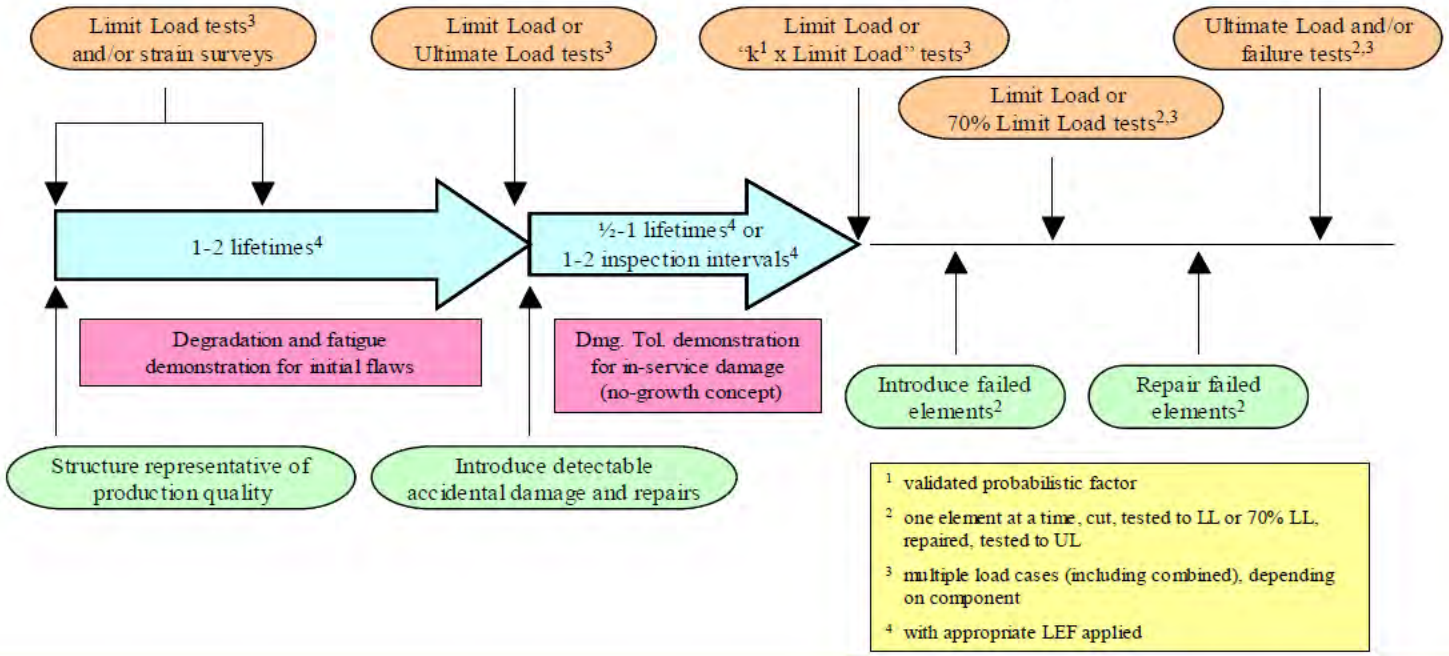
Composite Certification – Damage Thresholds

Substantiation: Test/Analysis Pyramid (Building Block)



Example Full Scale Structural Testing Sequence for Transport Category Aircraft

- ***Testing details will be application- and experience-dependent and must be negotiated with regulating agency***



Composite Certification – Damage Thresholds

Conclusions*:

- EASA does not approve inspection standards or methods, but accepts them as part of a process, project etc - provided that they are shown to be validated, applicable, and repeatable
- Technology, and technology application, changes must not reduce the existing 'acceptable' level of safety
- Limited specific content regarding NDI or NDI methods in the requirements
- TCH to accept new methods for 'certifiable' steps
  - icw POA, PART145 considerations etc (need for Safety Management Systems etc)
- demonstrate confidence – introduce use of parallel process not affecting existing airworthiness processes

*Note: This presentation was reviewed FAA. Also see, see support slides

Composite Certification – Damage Thresholds

Conclusions:

- NDI Challenges:
  - often assumes expected damage modes and locations
  - link between NDI indication and Residual Strength**?
  - many interesting laboratory methods…
    - few are practical and/or cost effective, particularly for in-service use

** Note: current Airworthiness Rulemaking Advisory Committee (ARAC) task in progress - changes to CS25.571 F&DT requirements (includes move towards 'performance' based requirements (fracture mechs, semi-prob etc), management of Structural Damage Capability (SDC), e.g. wrt threshold definition, and Large Damage Capability, (LDC))

Questions?

Support Slides

Opinions on Current State of Composite Inspection

Detect damage, monitor part quality but what about supporting residual strength predictions?

- Excellent safety management for most defects originating in the factory
  - Metal weak bonds & composite weakened bonds remain an issue
  - "Allowable damage characterization" remains a challenge (conservative and structural test extensive)
- Field practicality
  - Composite damage tolerance to facilitate practical maintenance
  - Most current field inspection procedures using NDI are triggered by visual evidence to measure the full extent of damage but are not quantitative for accurate damage tolerance assessments

Recommended Composite NDI Research

(towards a goal for measuring useful damage metrics)

- Composite damage tolerance assessments should include NDI measurements to identify the most reliable and accurate methods of determining the effects of given damage states on growth and residual strength
- NDE to determine "weakened composite bonds" should measure local stiffness and attenuation that suggest lost load paths and reduced strength
- More work on the structural integrity of composites exposed to fire and locally high temperatures
- More work on the NDE of aged composite structures, with some focus on bonded joints and repairs, followed by destructive testing and inspection

Production Organisation Approval PART 21, Sub. G – NDI:

21.A.147 Changes to the approved production organisation

(a) ….each change to the approved production organisation … significant to the showing of conformity or to the airworthiness … particularly changes to the quality system, shall be approved by the competent authority

GM 21.A.147(a) Changes to the approved production organisation – Significant changes

1 Changes to be approved by the competent authority include:

- significant changes to production capacity or methods…
- changes in the production or quality systems …important impact on the conformity/airworthiness of each product, part or appliance.

NDI – not explicitly mentioned, but implied

2 …ensure that changes do not result in non-compliance … competent authority and approval holder to establish a relationship … will permit the necessary evaluation work to be conducted before the implementation of a change

Maintenance Organisation Approval PART145 – NDI:

PART 145.A.30(f), AMC 145.A.30(f) Personnel requirements

2. Appropriately qualified means to Level 1, 2 or 3 …EN 4179 dependant upon the non-destructive testing function to be carried out.

5. Particular NDI means; Dye penetrant, magnetic particle, eddy current, ultrasonic and radiographic methods including X ray and gamma ray

6. …new methods …not limited to thermography and shearography, …not specifically addressed by EN 4179. Until such time as an agreed standard is established such methods should be carried out iaw particular equipment manufacturers recommendations including any training and examination process to ensure competence of the personnel with the process. - iaw TCH specs and intent

Define damage and defects – terminology to aid communication:

Category	Examples (not inclusive of all damage types)
Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)	**Barely visible impact damage (BVID), scratches, gouges, minor environmental damage, and allowable mfg. defects that retain ultimate load for life**
Category 2: Damage detected by scheduled or directed field inspection @ specified intervals (repair scenario)	**VID (ranging small to large), deep gouges, mfg. defects/mistakes, major *local* heat or environmental degradation that retain limit load until found**
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 that must retain limit load until found by 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, exploding gear tires, severe in-flight hail)**
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, which must be reported by operations for immediate action**

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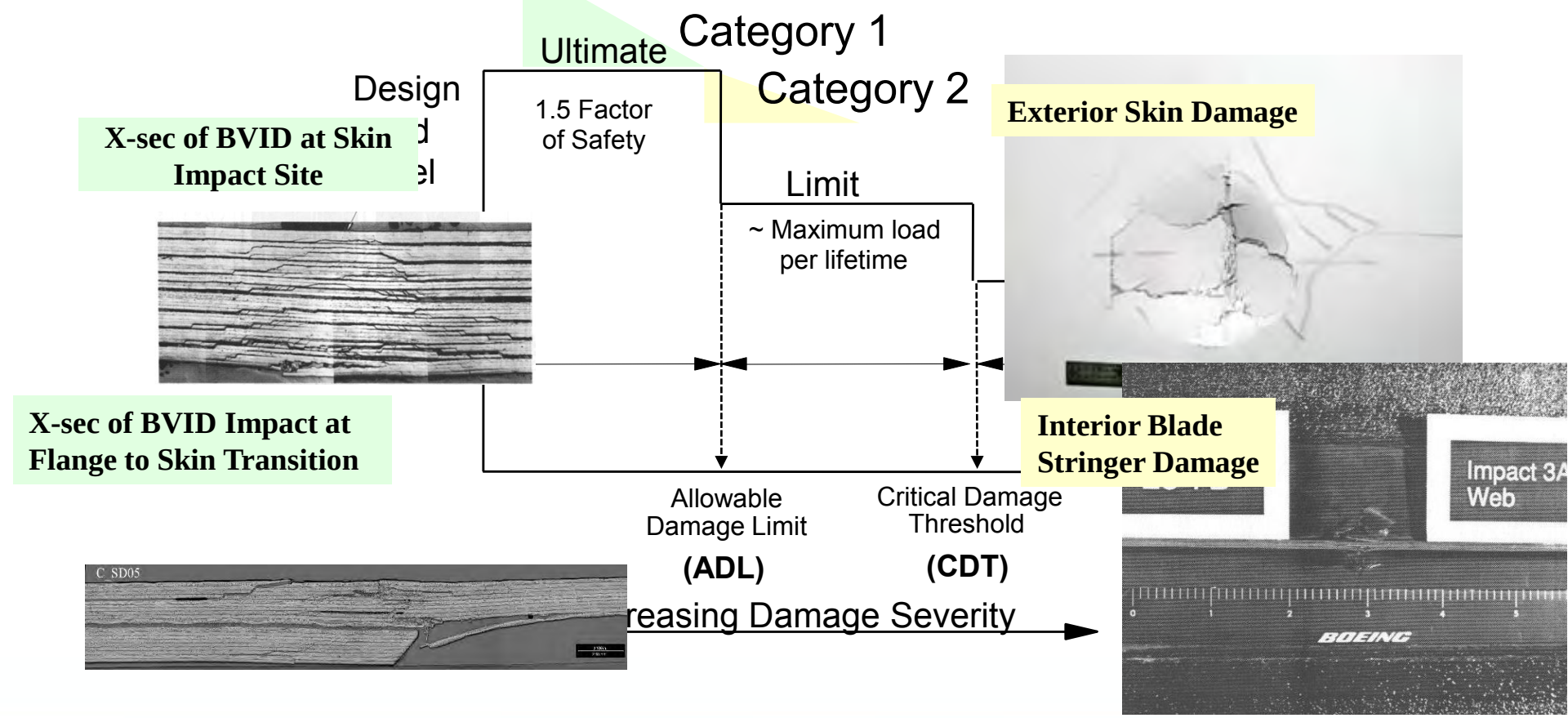
Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable manufacturing defects)

Category 2: Damage detected by scheduled or directed field inspection at specified intervals (repair scenario)



Composite Certification – Damage Thresholds

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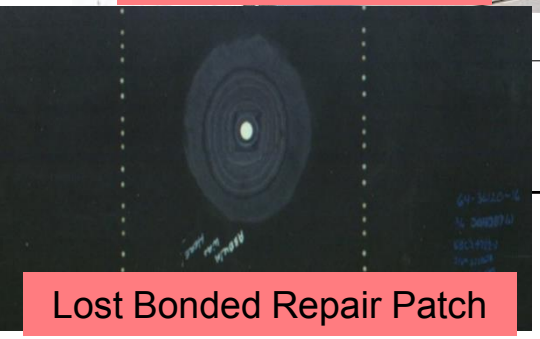
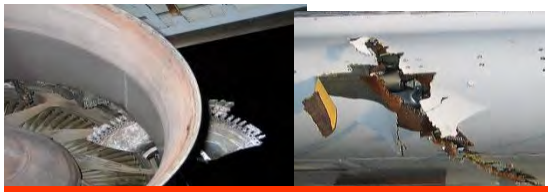
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)

Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)

Accidental Damage to Lower Fuselage

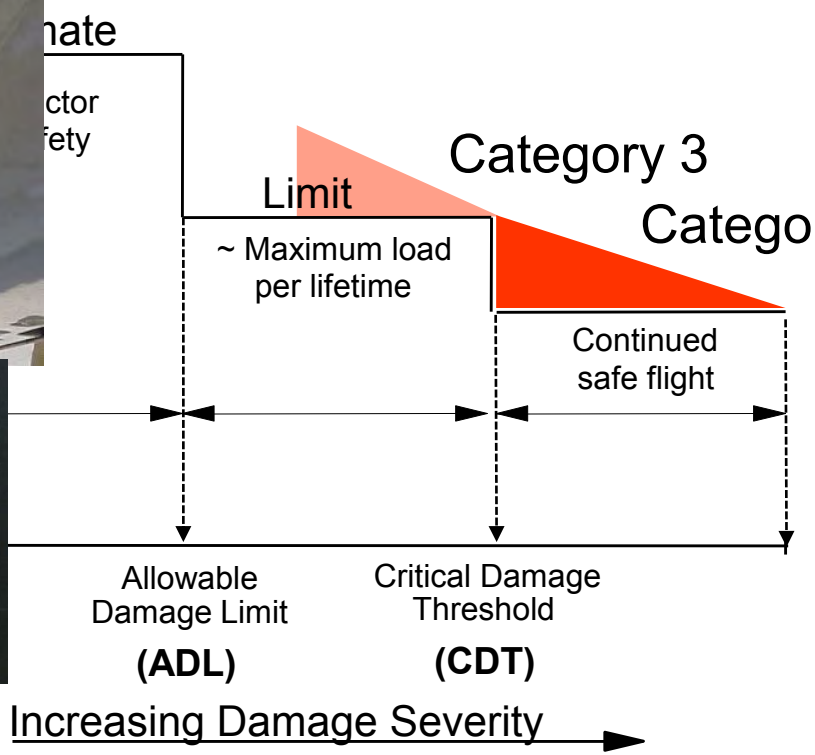


Lost Bonded Repair Patch



Disk Cut Through the Fuselage to Reach Opposite Engine

Severe Rudder Lightning Damage



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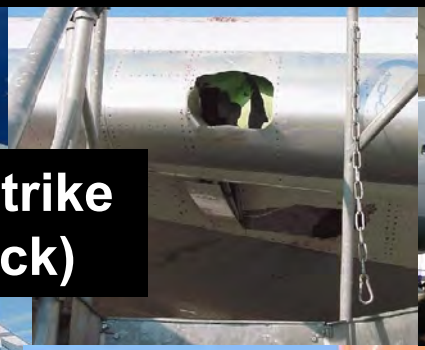
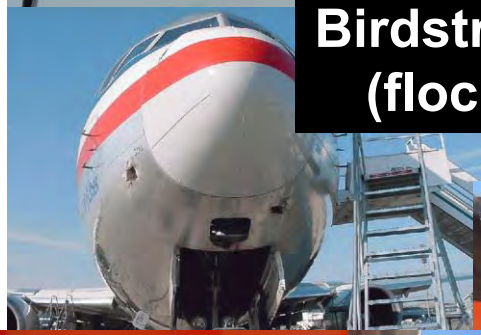
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)



Birdstrike (flock)

Maintenance Jacking Incident



Propeller Mishap

Birdstrike (big bird)

This is not the threat…it is obvious

(although determination of damage bounds and repair could be a problem) :

Composite Certification – Damage Thresholds

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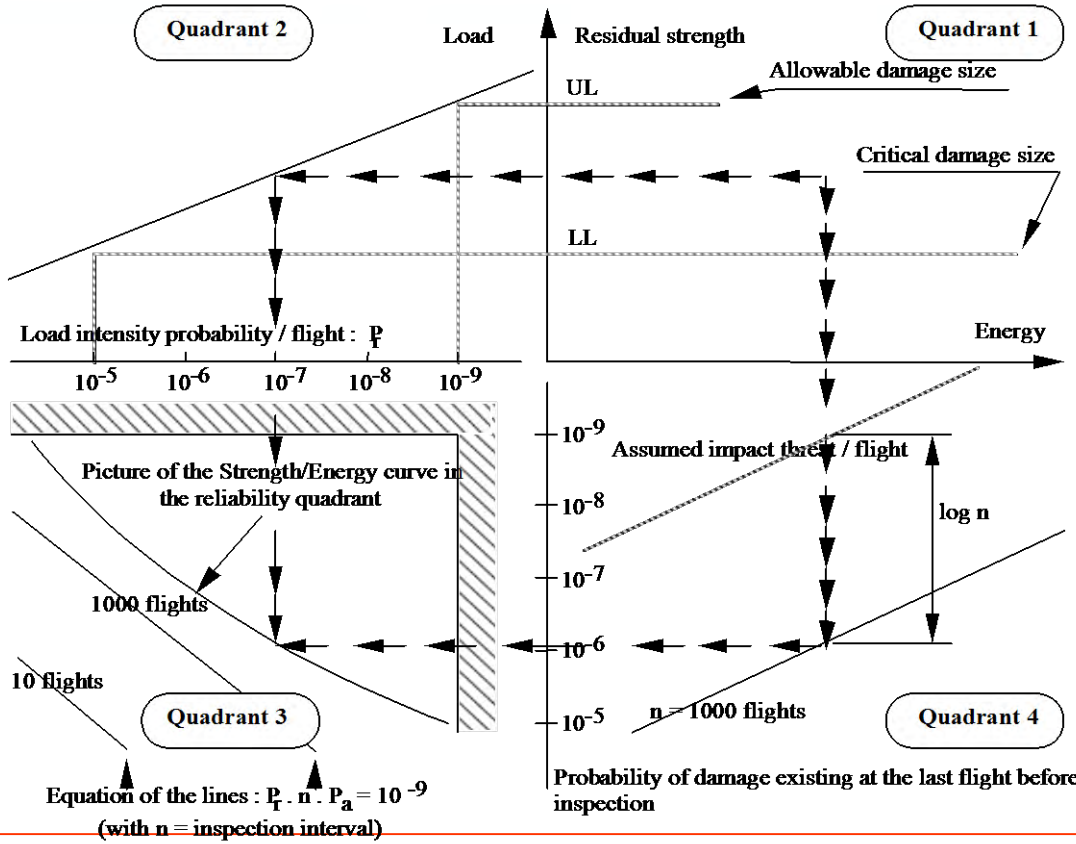

Simplified Probabilistic Method for Determining Inspection Intervals
(from CMH-17 Fig. 12.2.2.4.2)

- semi-probabilistic compliance
(only use supported by an extensive database and early agency agreement)