EUROPEAN AVIATION SAFETY AGENCY
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ICAS Biennial Workshop - 2011

Certification and Continued Airworthiness Issues for Composite Structures


Richard Minter

Head of Structures

EASA Certification Directorate



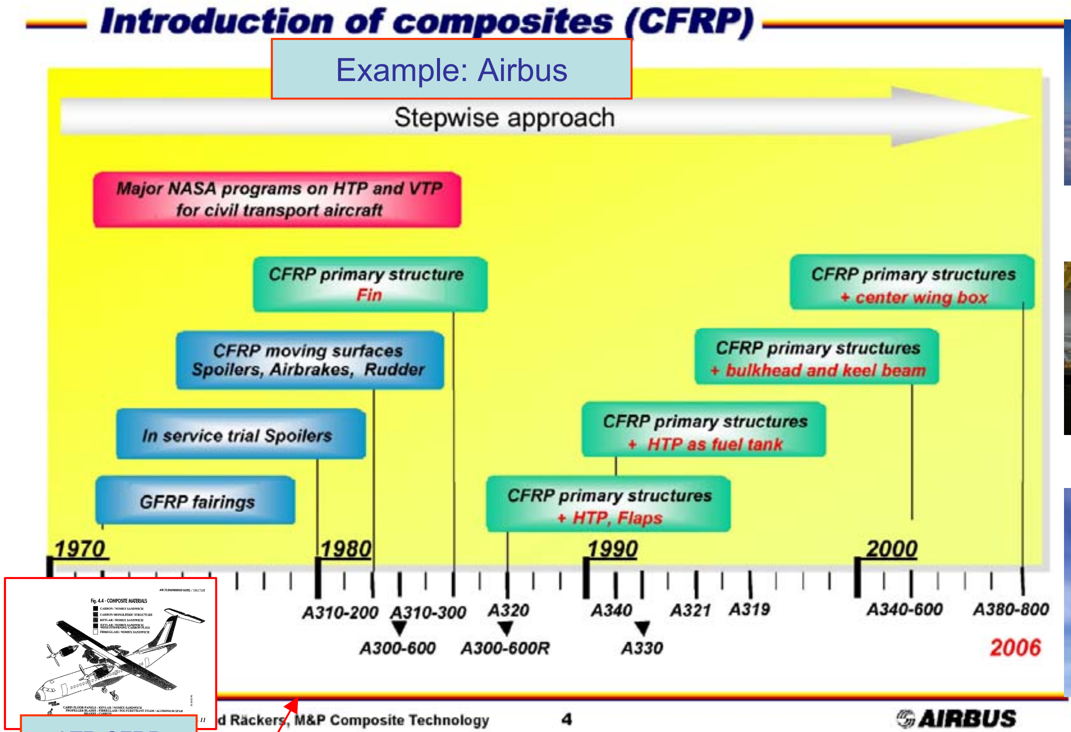
Your safety is our mission.

Overview

- Background
- Certification of Composites
  - General principles
  - Current practice and Issues
- Continued Airworthiness
- Related EASA activities and future areas of interest
- Conclusions

EASA Composites certification and CAW - background

- Increasing use of composites in critical structural applications:

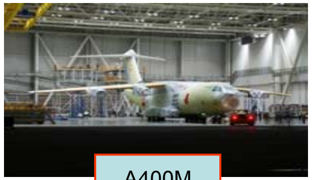


ATR CFRP wing box 1980s

generally good experience

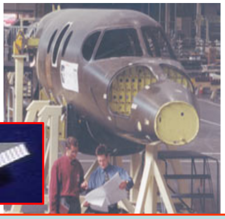
A380 (GLARE) skin panels

Composite use is well established in rotorcraft & small aircraft



A400M

A350 composite wings, fuselage



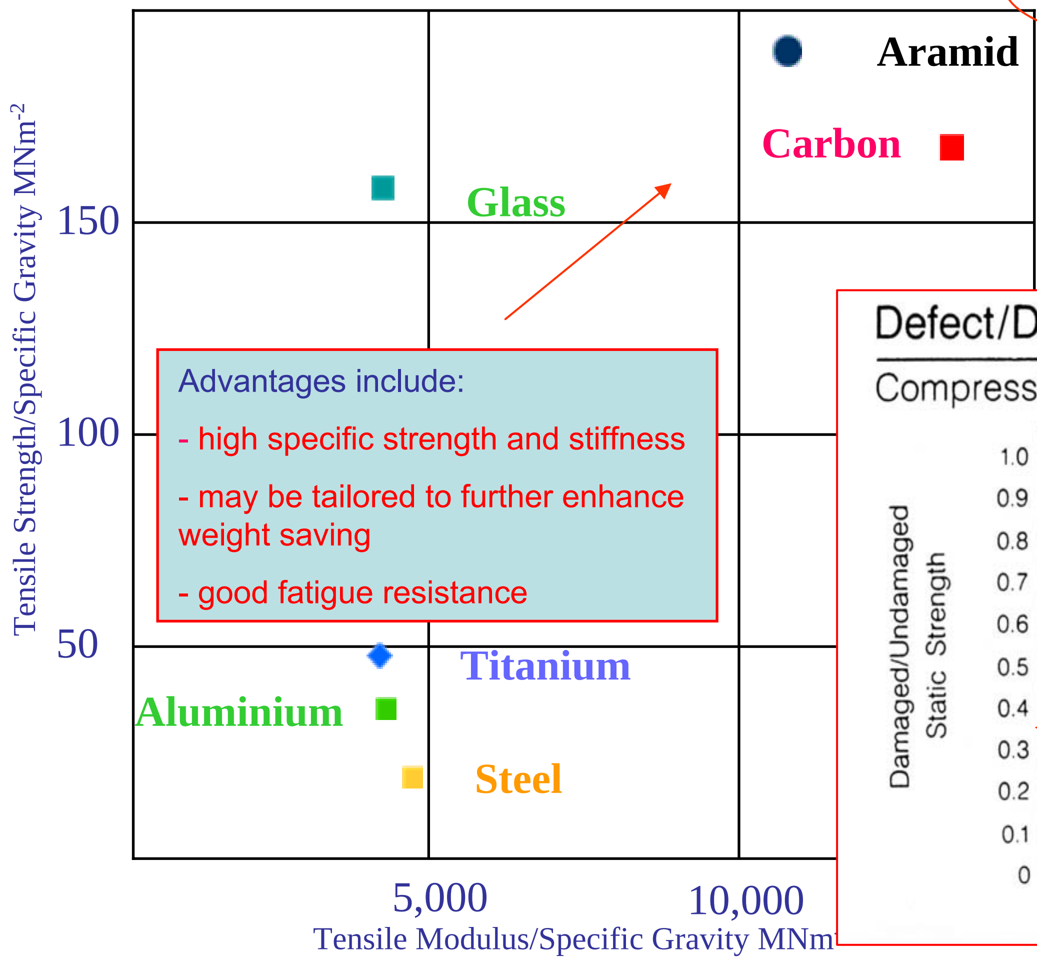
HBC4000 - CS 25 Honeycomb Sandwich fuselage)

Developing applications:
- undercarriage links
- large propeller blades
- more airframe applications
- extended engine applications (fan blades, open rotors etc)
- continued material form evolution (braiding, ceramic matrix)

Potential concerns include:

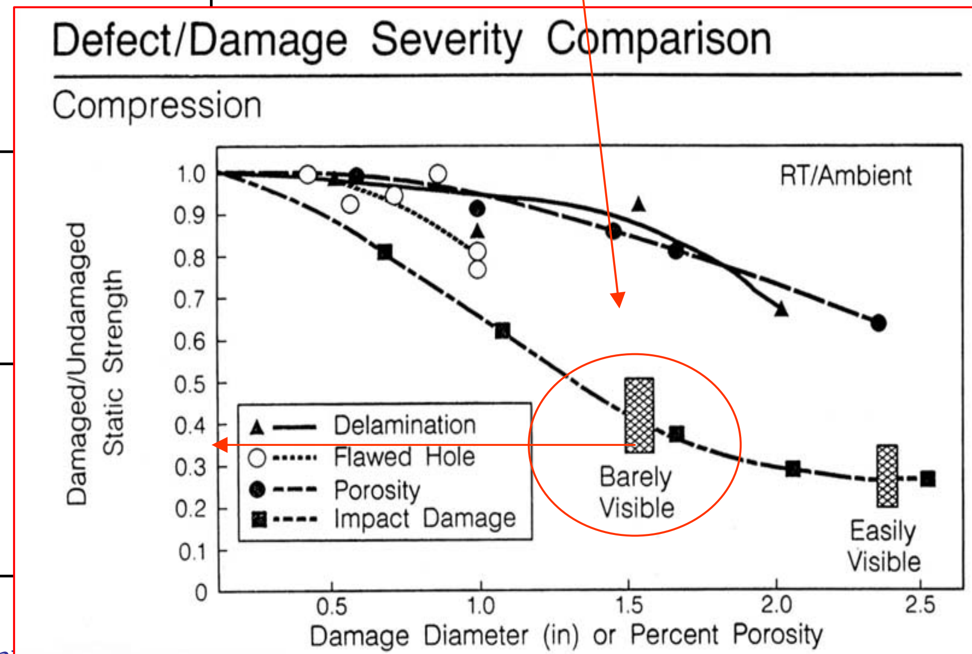
- low out of plane, compressive, and shear strength
- Impact sensitive
- Barely/Non Visible Damage (BVID/NVD)
- strength/stiffness reduction for **critical damage modes**
- damage modes (can be mixed), failure loads, and locations can be difficult to predict

Why we use composites



Advantages include:

- high specific strength and stiffness
- may be tailored to further enhance weight saving
- good fatigue resistance



Certification of composite structure

- EASA Composites certification – general principles
  - Certification is largely based on generic requirements in the Certification Specifications (CS) that apply whatever the material used in the airframe construction.
  - EASA advisory material AMC 20-29 provides extensive guidance on how to show compliance with static strength and damage tolerance requirements when using composite materials for airframe structures.
  - There are certain specific prescriptive requirements that have largely been developed (and hitherto limited) based on metallic airframe structure and experience, therefore it has been necessary to ensure that a change to composite does not degrade the level of safety provided. This is achieved by showing equivalent or better behaviour to that of a comparable metallic design and ensuring all realistic threats are addressed.

Certification of composite structure

- EASA Composites certification – general principles cont.
  - The regulatory authorities pay particular attention to new and novel design features and may raise special conditions (per Part 21) if the existing CS does not address such items.
  - Composites are no longer novel in a generic sense, but some of the recent applications of composites are relatively unproven and the materials are being continually developed.
  - The Agency endeavours to take a proactive approach to safety, trying to anticipate potential issues.
  - As a result we will ask more questions as the collective experience of industry and regulators is still limited compared to metallics.

Certification of composite structure

- Some challenges for composite use and certification
  - environment (moisture and temperature reduce strength)
  - poor heat and electrical conduction (lightning strike)
  - low out of plane strength and bond quality
  - can be brittle (vulnerable to load peaks, impact damage)
  - engineering property variability (strength and fatigue)
  - prediction of failure loads, modes, and locations
  - damage detection (delamination, Barely Visible Impact Damage) and evaluation of residual strength
  - fire behaviour (toxic fumes, fibre release, post fire strength)
  - methodologies for design and certification are necessarily different to those for metallics

Certification of composite structure

- Certification current practice and issues
- While many of the above challenges are now in principle well understood and managed, the following issues currently attract our attention:
  - Full scale test
  - Crashworthiness
  - Large scale blunt impact damage
  - Appropriate failure scenarios for bonded structural elements
  - Advance consideration of repairs
  - Reliability of Detection of damage

Certification of composite structure

- Certification issues cont.
- Full scale test is required to show compliance with static strength and damage tolerance requirements and is an expensive process for the applicants
  - Different failure modes attract different knock down factors for environment and variability (e.g. buckling, dependent on modulus, may not be affected as much as other properties) and unrealistic load levels may promote premature failure
  - Interfaces with metallic structure - may require two specimens
  - Adequate representative component tests are needed to address failure modes that will not be interrogated in full scale test to ensure a complete and adequate test pyramid
  - The trend is that environmental and variability factors are reducing with improved materials and processes, but not in all cases
  - Compromises are often required and must be substantiated

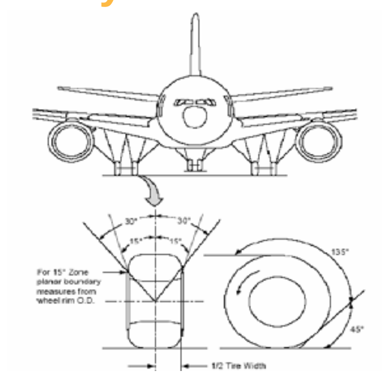
Certification practice cont.

Special conditions are used to address Issues that are not explicitly addressed in the Certification Specifications

fire

lightning

tyre debris



crashworthiness

engine debris

The objective is to maintain the safety level relative to that provided by metallic structure – this can be difficult to define and quantify!

Certification of composite structure

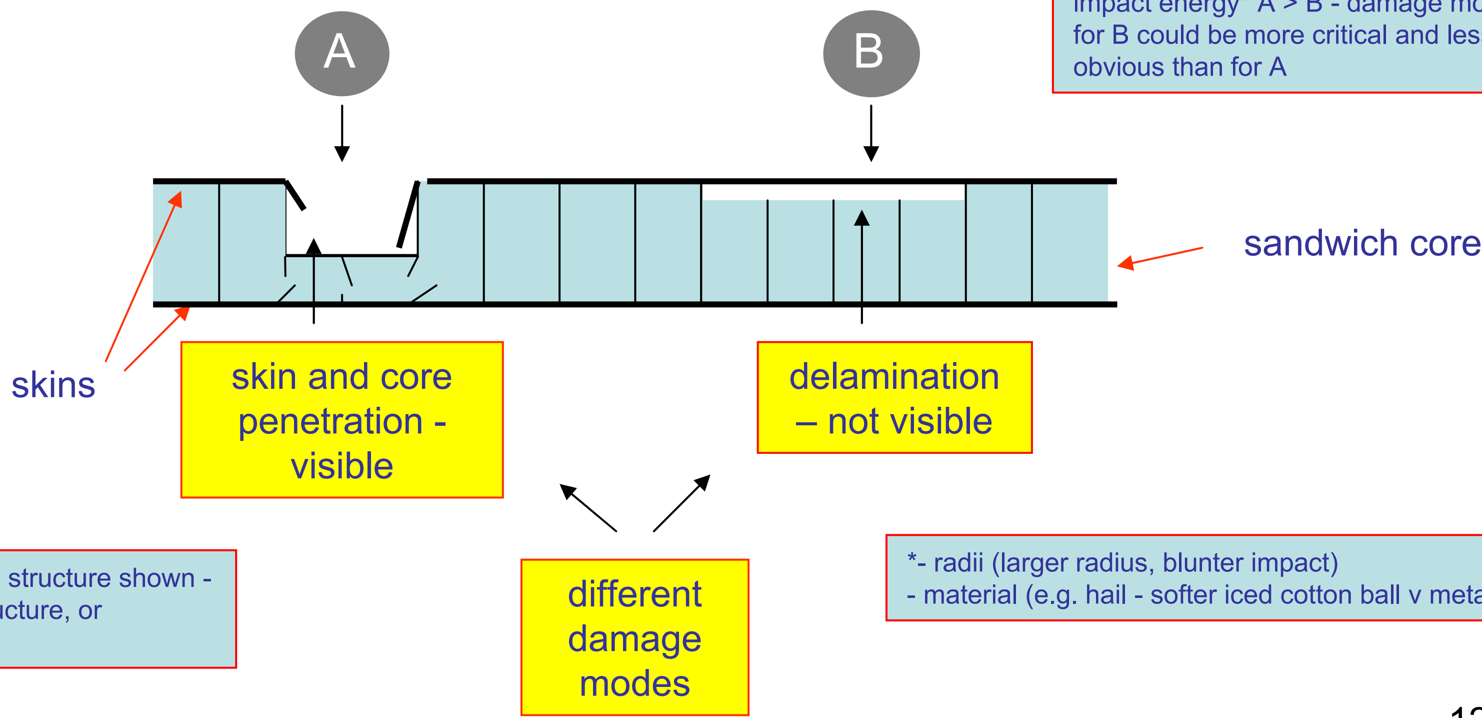
- Composites certification practice cont.
- Two key examples of special conditions are:
  - Crashworthiness, whereby the use of composites may change the response of the cabin structure in an otherwise survivable accident. Testing and analysis is required to substantiate that the behaviour of the airframe is acceptable compared to existing metallic designs and recognised survivability criteria.
  - Fuel tank impact resistance, for which current requirements address only the fuel tank covers as experience for conventional wing panels has generally been good. Fuel tank skin panels at risk from impact due to tyre and engine debris must be assessed to demonstrate equivalent or better behaviour.

Impact Threats: many possible damage modes, a function of

- Part: material, geometry etc
- Impactor: material (e.g. stiffness, dynamic behaviour), geometry, energy, orientation

(See also Appendix 1 and related EASA research on hail and large scale blunt impact)

impact energy* A > B - damage mode for B could be more critical and less obvious than for A



Example: sandwich structure shown - could be bonded structure, or monolithic structure

*- radii (larger radius, blunter impact)
- material (e.g. hail - softer iced cotton ball v metallic)

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Impact Threats:– Damage Severity/Certification Loads

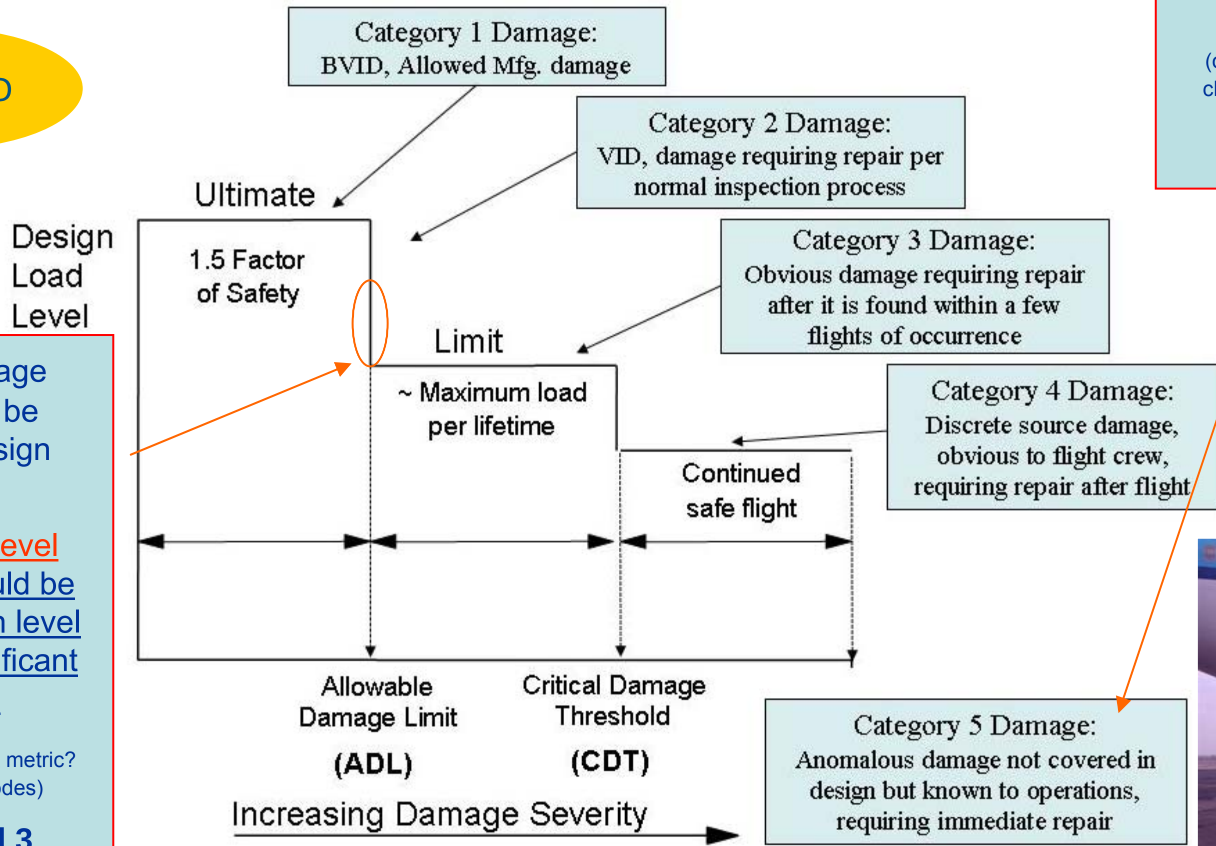
- **Cat 5** not major concern
if known
But, if not known

(or not reported) we need to minimise chance of missing damage indication

- relaxation

- 'blame culture'

EASA R&D



BVID damage should not be concern/design driver

- but BVID level indication could be only indication level for more significant damage

- is dent the correct metric? (many failure modes)

Cat 2 and 3

EASA R&D

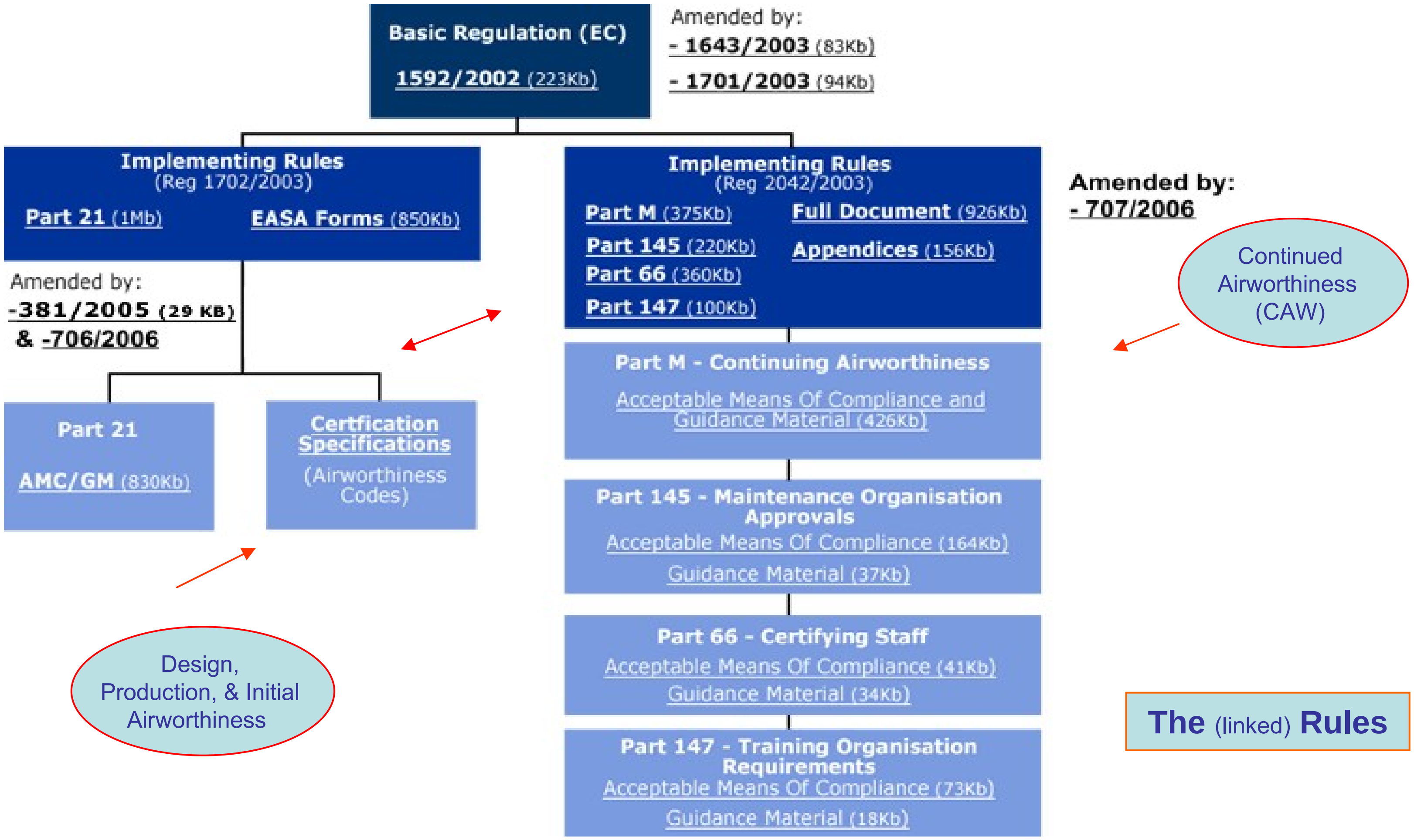
Certification and Continued Airworthiness of bonded composite structure

- Bonded structure and especially repairs and the design and CAW processes associated to them are of concern

- This is an open issue on current projects and EASA is considering guidance on their development

Certification and Continued Airworthiness of bonded composite structure

- Design, Production, and CAW rules are linked - properties built into production/repair process

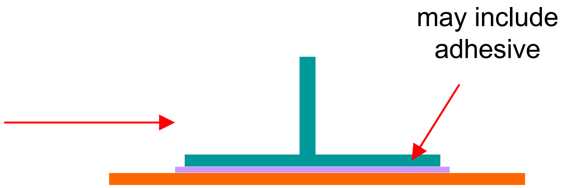


Bonded Structure Definitions (AMC 20-29):

Co-cured Structure: Uncured components cured together
(may include structural plies common to bonded components (adherends))

Structural Bonding: A structural joint created by the process of adhesive bonding, comprising of <u>one or more previously cured composite</u> or metal parts
(referred to as adherends, includes Secondary Bonding, Co-bonding)

Bonded repair scenario



Disbond: An area within a bonded interface between two adherends in which an adhesion failure or separation has occurred. It may occur at any time during the life of the substructure and may arise from a wide variety of causes. Also, colloquially, an area of separation between two laminae in the finished laminate (in this case, the term "delamination" is preferred).

Weak Bond: A bond line with mechanical properties lower than expected, but without any possibility to detect that by normal NDI procedures. Such situation is mainly due to a poor chemical bonding.

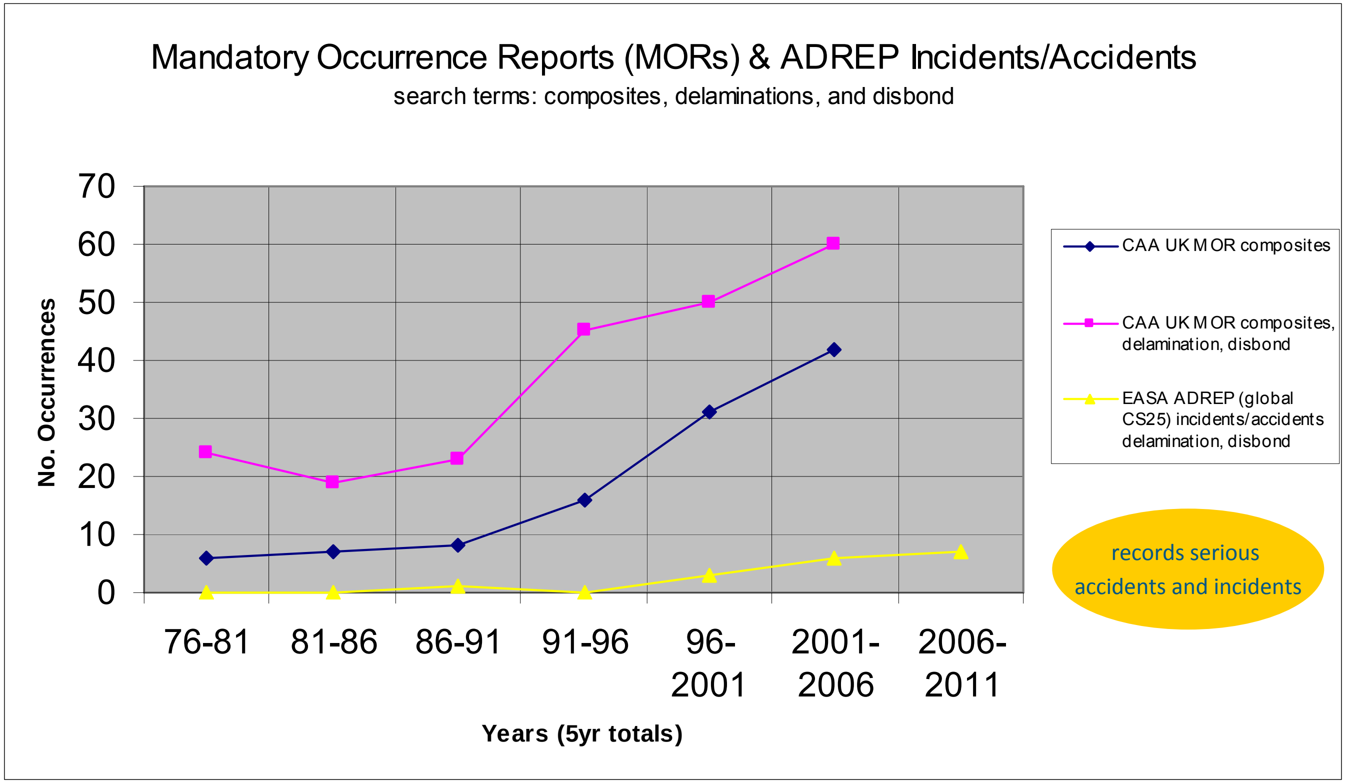
Ref. FAA Policy Memorandum 'Bonded Joints and Structures – Technical Issues and Certification Considerations' PS-ACE100-2005-10038

Bonded Structure Concerns:

Many more recent Primary/PSE/Critical Structure examples: Production and in service issues: e.g.

- Primary Structure failure following failure to inspect /find damage in impacted structure which was already subject to an AD addressing disbond.

- Repairs – various control surface and repair failures



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Bonded Structure – Existing Regulations:

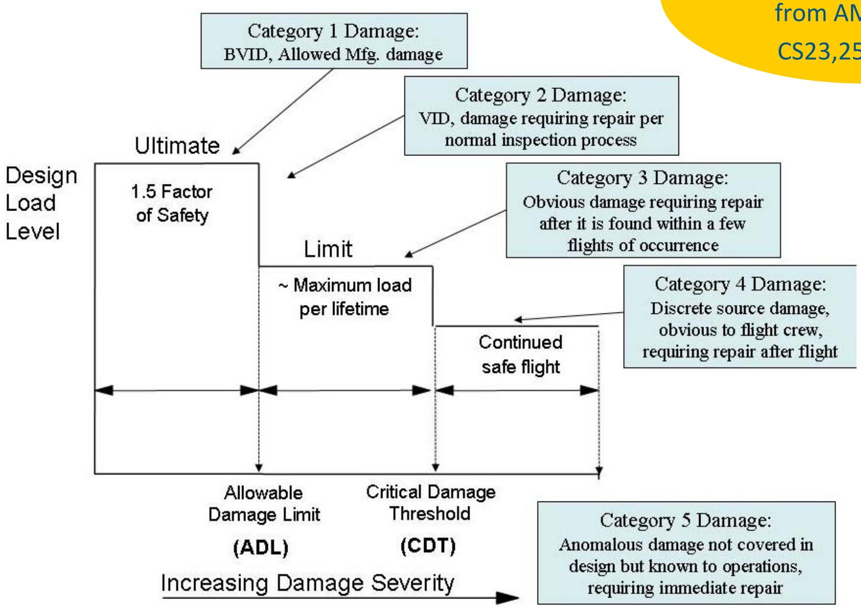
- few certification rules are specific to composites… *for bonded structure…*

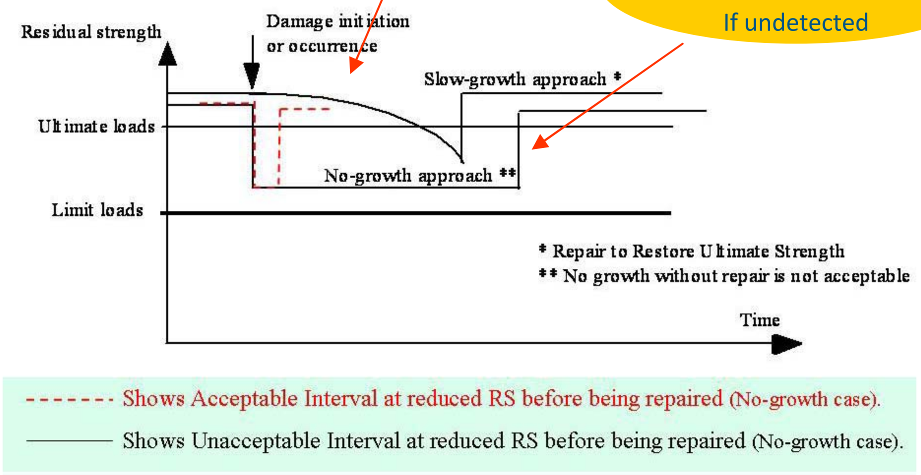
CS 23.573(a)(5): ‘ …for any bonded structure, the failure of which would result in catastrophic loss of the airplane, the limit load capacity must be substantiated by one of the following methods.

Damage Tolerance requirements for composites from AMC 20-29 CS23,25,27,&29

Slow growth similar to metallic structure

Potentially less safe than metallic structure If undetected





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CS 23.573(a)(5) continued…

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

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

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

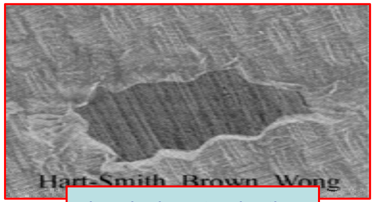
must be detected within a few cycles

not intended to address poor process

existing techniques not adequate*

- not practical for CS25
- does not address durability issues (weak bond etc)

aging adhesive



chemical contamination: nylon release fabric causes interfacial failures

* FAA Policy Memorandum 'Bonded Joints and Structures – Technical Issues and Certification Considerations' PS-ACE100-2005-10038

Bonded Structure – Regulatory/Industry Concerns and Activities:

Issues:

- CS23.573 allows Bonded Repair sized to Limit Load capability, if the repair is assumed to be failed.
- AMC 20-29 bounds CS23.573 with further guidance
    - the failed repair must be readily detectable
- 'Weak Bonds' and 'Tight Disbonds' are not detectable

Regulatory/Industry Activities:

- Composite Material Handbook-17 (CMH-17) Delamination/Disbond WG activity Regulatory/Industry WG – objective to develop clarifying Policy regarding bounds of acceptability for Bonded Repair and/or need for Bolted Repair
- Increasing industry R&D (Lufthansa Tech, SEGEM etc)

- Detection of damage and design assumptions are linked

- The ability to detect damage and act appropriately taking into account the type of structure requires training based on techniques that produce an acceptable probability of detection of all the related damage

- Research is being conducted into detection issues

- The effects of damage and the processes of justification of residual strength and damage detection and disposition need to developed in line with advances in material systems and structures

- Ageing composites?
  - Generally good experience so far, however, bonded honeycomb panels and moisture absorption in honeycomb structures remain an ongoing concern.
  - No specific concerns about fatigue (in comparison to metallics), assuming reasonable design practices are adhered to and manufacturing quality maintained.
  - As we move forward it is anticipated that further optimisation of the design process and pressure to save weight will increase the need to ensure the robustness of analysis and test methods.

- Unknowns
  - Is the expected impact and other damage assumed in certification continuing to prove realistic?
  - Is there unexpected deterioration, cracking etc?
  - A fleet leader programme for inspection and feedback to the TCH is recommended

  - As for metallic structure; load levels influence performance
  - Regular reviews of operational usage should be conducted

Related EASA activities and future areas of interest

- External Working Groups with which EASA is involved that help support our approach to Certification and CAW issues.
  - CMH-17
    - Developing detail means of compliance supporting the philosophies of EASA AMC 20-29 / FAA AC20-107B and other regulatory guidance
  - FAA/EASA/Industry WG
    - Discussing current concerns and developing an action plan for potential rulemaking and advisory material in the areas of bonded structure and crashworthiness amongst others
  - CACRC (Commercial Aircraft Composite Repair Committee an SAE Group)
    - Developing material on all aspects of composites repair
  - SHM (SAE Group)
    - It is recognised that industry will seek more credit for SHM systems as they are developed. We will endeavour to support this process.

Related EASA activities and future areas of interest

- EASA Research on Composite Structure

  - Visual Inspection of Composite Structures
    (EASA R&D 2007/3 - DLR)
  - Low Velocity/High Energy Blunt Impact
    (OP06 EASA R&D CODAMEIN - Bishop)
  - Hail Threat Standardisation
    (OP25 EASA R&D 2008/05 – Qinetiq/UK METOffice)
  - Impact of Preloaded Structure
    (OP24 EASA R&D LIBCOS - DLR)

  see APPENDIX 1 for more details

  EASA Focal for these composite WG and research activities is Dr. Simon Waite

CONCLUSIONS

- Composites are no longer novel in a generic sense, but some of the recent applications of composites are relatively unproven and the materials are being continually developed.
- Specific issues that deserve particular attention are:
  - Crashworthiness
  - Design and certification of bonded structure, including repairs and the type and extent of failures to be considered
  - Blunt impact
  - Training of staff in design, production and maintenance

- CONCLUSIONS cont.

- The Agency endeavours to take a proactive approach to safety, trying to anticipate potential issues.

- Research and participation in various international working groups is supporting the certification and CAW process by increasing our knowledge of the key issues for composites.

- Industry should expect more questions whilst our collective experience grows, yet remains limited compared to metallics.

Thank you

YOUR QUESTIONS are WELCOME

- EASA Research on Composite Structure

  - Visual Inspection of Composite Structures
    (EASA R&D 2007/3 - DLR)

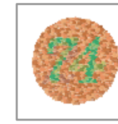
  - Low Velocity/High Energy Blunt Impact
    (OP06 EASA R&D CODAMEIN - Bishop)

  - Hail Threat Standardisation
    (OP25 EASA R&D 2008/05 – Qinetiq/UK METOffice)

  - Impact of Preloaded Structure
    (OP24 EASA R&D LIBCOS - DLR)

EASA Research: Composites – Visual Inspection

Visual Inspection 1: Objective - Better understand significance of colour, lighting, finish to successful detection of damage (classic dent)



CS 25.571: *Damage Tolerance and Fatigue Evaluation of Structure:*

‘(3)…..inspections or <u>other procedures</u> must be established as necessary to prevent catastrophic failure, and must be included in … Instructions for Continued Airworthiness required by CS 25.1529’

80-90% of inspections are visual

EASA AMC 20-29 says:

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

- ability to detect damage may vary with colour, lighting, <u>finish</u> etc… R&D in progress

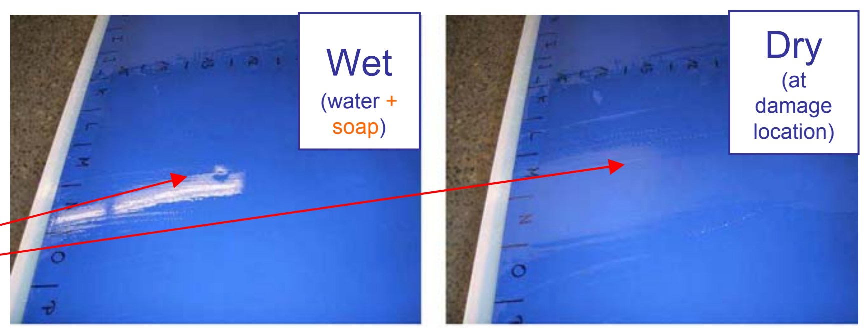
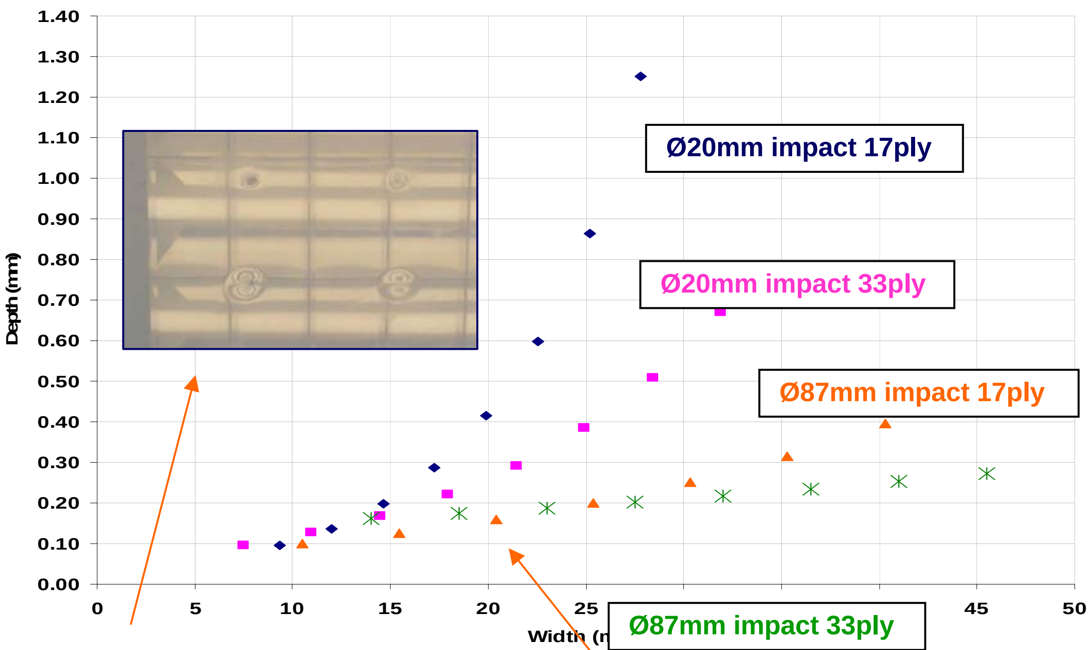
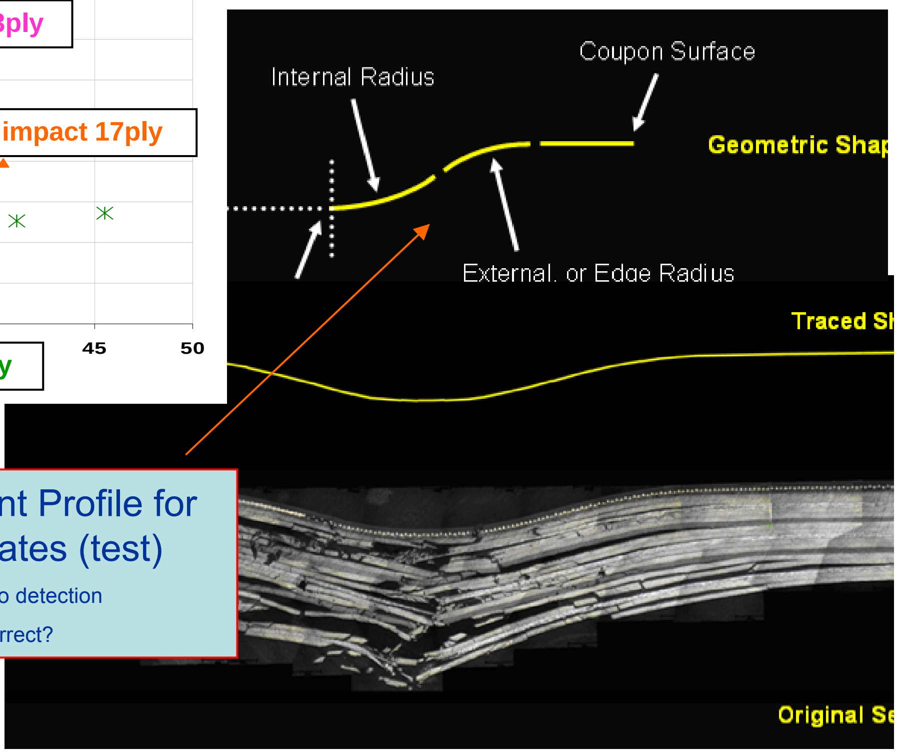


Figure 60: Surface wetting, to improve detectability of dents on matt surface.

EASA Research: Composites – Visual Inspection



R&D – Damage Metrics
Inspection/Detection Variables



Simulate* a range of dents and inspect for a range of size, colours, and finishes

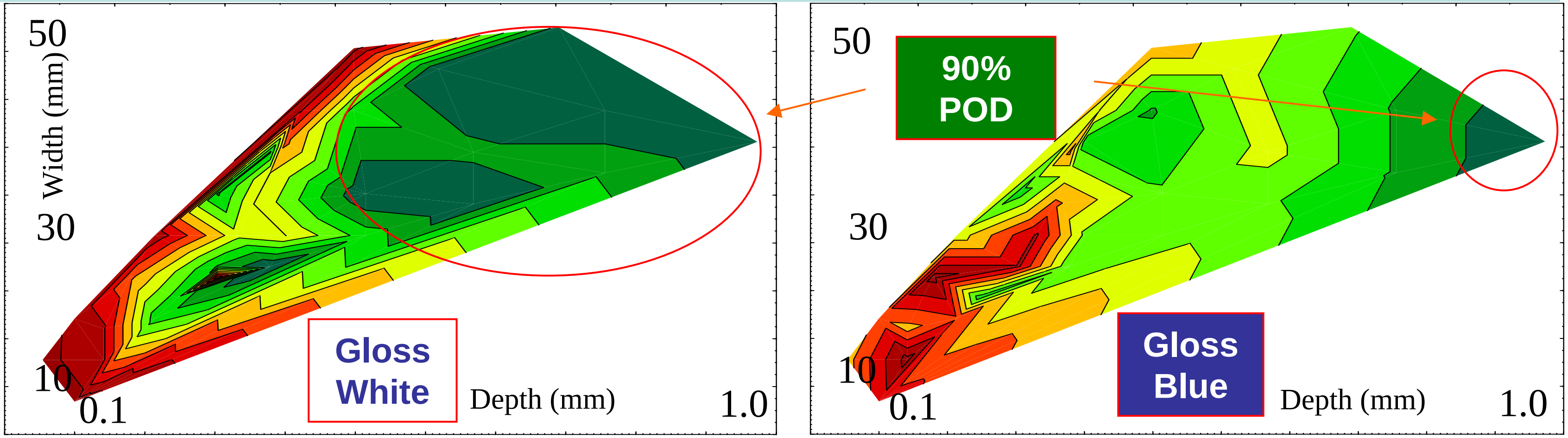
* CNC Plexiglass

Characterise Dent Profile for range of laminates (test)

- is the dent profile significant to detection
- is the classic 1 in impactor correct?

* **Reliability of Visual Inspection of Advanced Composite Aircraft Structures**' 2009, L.Cook, Prof. P.Irving, Dr. D Harris Cranfield University

Bi-variate (width/depth) Dent POD - gloss white v gloss blue



- multi-variate analysis could be required for POD (probability of detection) (rather than traditional single variate)
- ‘bigger’ is not always ‘better’, i.e. increasing w/d may reduce detection rate
- colour may change detection rates, e.g. detection rates for white > blue etc

(Note: damage associated with this level of indication traditionally has not driven design. However, it may be the only cue for more significant damage - TBD)

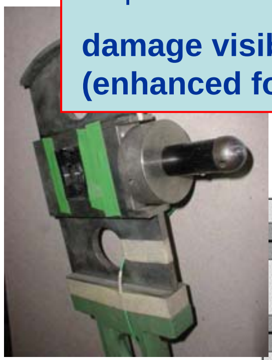
EASA Research: Composites – Visual Inspection

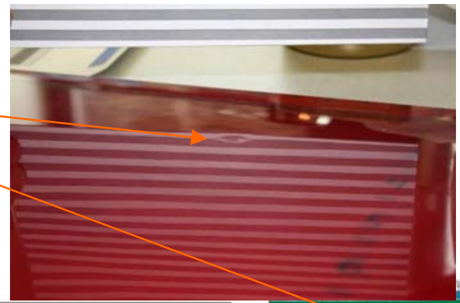
Visual Inspection 2: Objective - Better understand non-visible damage - representative structure, impactor definition, energy, and paint finish

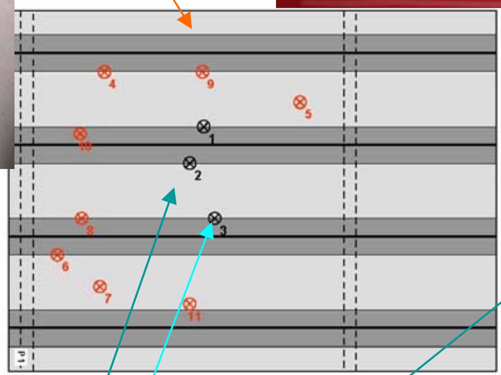
Φ 25.4 mm

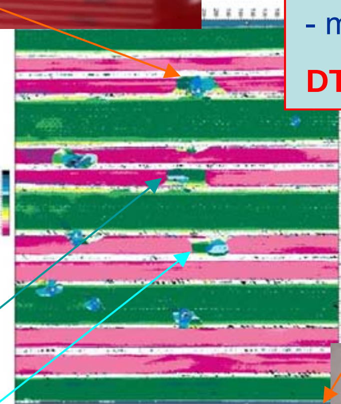
impact 9 - 60J

damage visible (enhanced for photo)



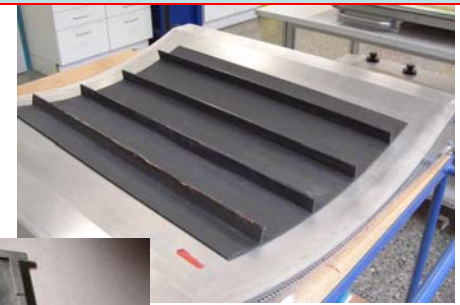






- **larger impactors** (more realistic threat?)
- representative structure
- damage at reasonable energy levels
- damage not visible (>Allowable Damage Limits?)
- multiple impacts?

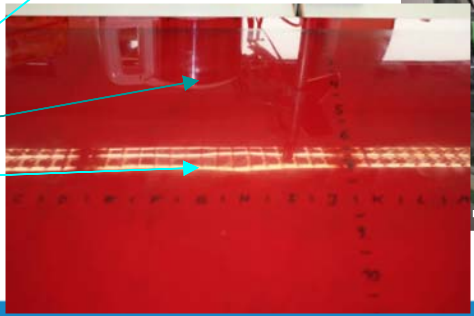
DT Design must account for these variables



Φ 320mm

impact 2 - 60J,
impact 3 - 75J

damage not visible



(EASA R&D 2007/03 – available on EASA web site): Provided evidence that a larger blunt impactor can produce non - visible damage at BVID energy levels in representative structure

EASA Research: Composites – Impact Threats

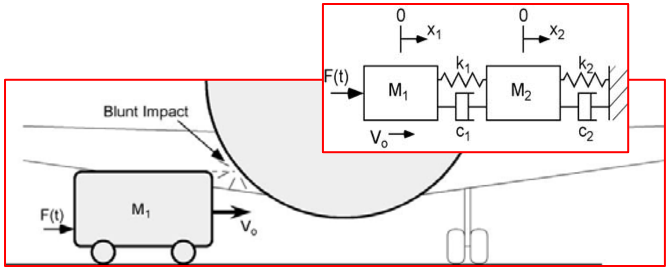
High Energy Low Velocity Blunt Impact: Objective – Better understand potential for large damage to remain undetected

(complement existing research* - FAA/EASA/Boeing/Airbus)

AMC 20-29 para.8(c) says:

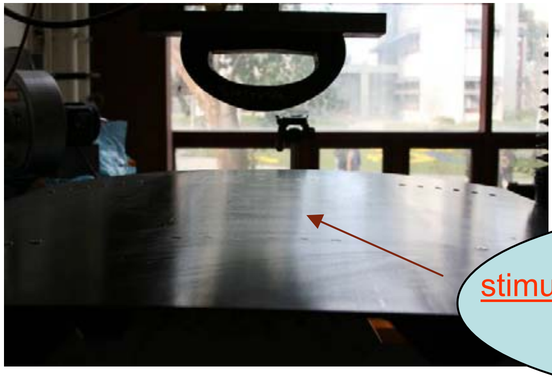
‘Cat 5: Severe damage from known incident

…..not covered by structural substantiation procedures’



- *material change not to reduce the existing ‘acceptable’ level of safety*

- Non-Visible/BVID indication issue not to reduce level of safety



Interesting results
stimulated discussion - potentially significant damage **not** externally visible

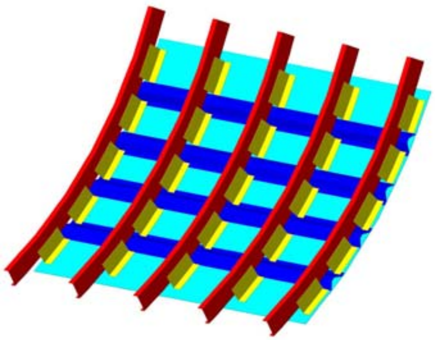
*hyonny@ucsd.edu

EASA Research: Composites – Impact Threats

High Energy Low Velocity Blunt Impact (OP06 CODAMEIN – just started):

Experimental identification of key phenomena and parameters governing high energy blunt impact damage formation, particularly focusing on what conditions relate to the development of massive damage occurring with minimal or no visual detectability on the impact side

carbon skin/stringer - aluminium frame



EASA Priorities (further to Hyonny Kim work): :

Boundary Conditions:

- Aircraft level boundary conditions and impact dynamics (later programme – needs large budget and appropriate manufacturer)

Hybrid structure:

EASA to complement existing with R&D programme with impacted hybrid structure (with approximate extreme boundary conditions)

- provide comparison with all carbon structure behaviour

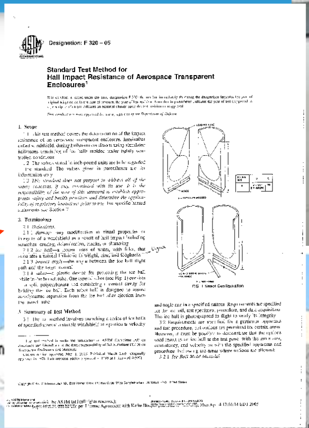
work just starting

- understand boundary condition sensitivity

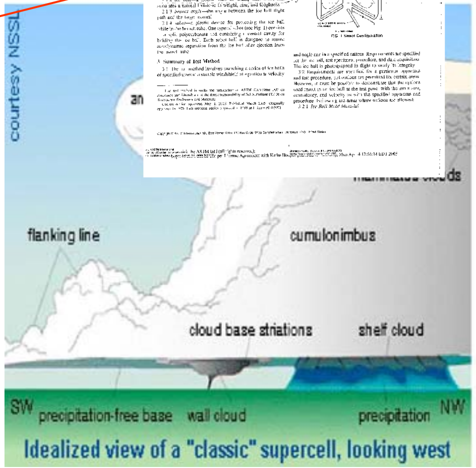
EASA Research: Composites – Hail Threat

Hail Threat: Objective – Define standardised hail impact threat (OP25 2008/05):

- using current global meteorological models (plus existing limited hail data)


Designation: F 320 – 05

Standard Test Method for Hail Impact Resistance of Aerospace Transparent Enclosures



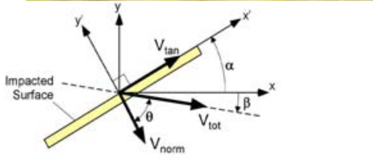
Hail is identified as a threat in AMC 20-29:

- Discrete source and more general DT threats
- Para 8a: 'currently few standards'

Standardisation:

- **Define threat** – consult with industry (using EASA report)
  - small F&DT threat – multi-strike
  - large discreet threat (CSF&L) (can we rely upon aircraft radar to avoid this?)
- **Manage threat by design**, e.g. per J. Halpin
  - confirm consistent damage modes through energy range up to these levels
- **Simulation method** (energies, geometries, stiffness (metallic, frozen cotton ball), orientation etc - TBD)

report available* - input to help define threat



Projectile and surface are both moving. Velocity vector V_{tot} describes the motion of the incoming projectile relative to the surface.
α is angle between surface and horizontal (+ccw w.r.t. x-axis)
β is angle between projectile relative path and horizontal (+ cw w.r.t. x-axis)
$\theta = 90 - \alpha - \beta$ is angle between normal and total velocity components of projectile

* http://easa.europa.eu/safety-and-research/research-projects/large-aeroplanes.php#2008op25

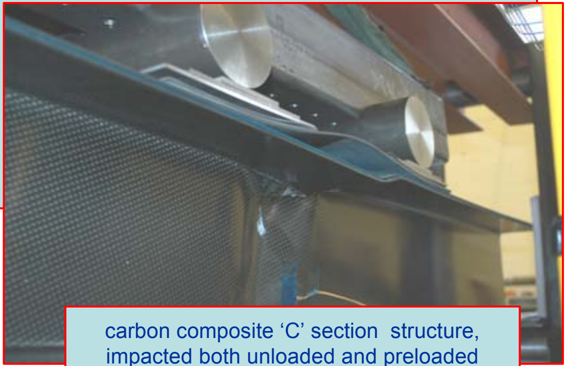
EASA Research: Composites – Preload/Impact

Impact of Preloaded Structure: Objective – Better understand relationship between material change, existing Means of Compliance (MoC), service experience, and existing level of safety.

Typically, representative pre-loads are not applied to structure during impact testing - is this significant? (different dynamic failure behaviour wrt metal, influence of BVID?)

Example: Bird Strike - operational structure is impacted when loaded

- **metal experience including impact test** (e.g. Vc, 4lb bird), **without flight loads provides 'acceptable level of safety'**
- **composite** material **behaviour** (typically quasi-brittle) **differs to that of metal**
- **does passing the same test, without load, provide the same level of safety for composites?**
- **preliminary CAA UK R&D suggests impact of loaded structure:**
  - **reduces (visible) damage area**
  - **reduces residual strength**



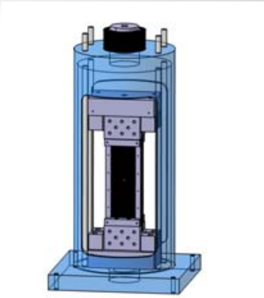
carbon composite 'C' section structure, impacted both unloaded and preloaded with 0.25kg birds at 70-80 m/s

Effect of Preload on Bird Strike Damage in Carbon Fibre Polymer Composite Beams P E Irving, A K Pickett, N K Bourne, A Mills, M Frost, G S Stevens, J Hurley, N Angelidis Cranfield University Civil Aviation Authority Report No CU/WA9/W30814E/62

EASA Research: Composites – Preload/Impact

Impact Preloaded Structure:

Final report in preparation



Recent EASA R&D (OP24 LIBCOS – publish soon)

- hard/sharp (3/8in metallic cube) and blunt/soft (1in glass ball) impactors
- simple 'representative' material & lay-up small panels (500mmx200mmx2.125-3.125mm)
- loaded (zero, tension, and compression)
- V = up to 200 m/s (60mm gas gun)
- Residual Strength (RSF wrt no impact/no load)

R&D suggests impact of loaded structure again:

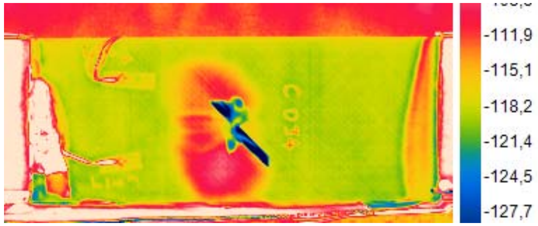
- reduces residual strength

- damage not visible **(limited visibility back face)**

	Loading	Preload	RSF: Notch impact damage	RSF: Delamination/ indent damage
Composite	Tension	0 0.25 % strain	0.37 0.48 – 0.53	TBD 0.66 – 0.75
	Compression	0 0.95Pb - 1.4Pb	1.0 0.96 – 1.02	0.84 0.67
Aluminium	Tension	0 0.25 % strain	TBD 0.76	TBD TBD
	Compression	0 1.5 Pb	TBD 0.93	TBD TBD

generally visible

Pb = buckling load



Thermographic image