EASA Composite Materials Safety Strategy

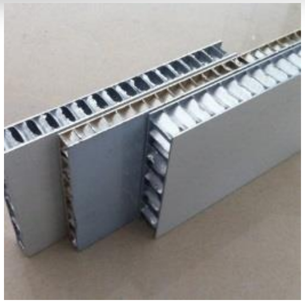
Sandwich Structure Meeting

icw FAA, Industry, & CMH-17 Disbond/Delmination TG

Koeln 18th October 2016

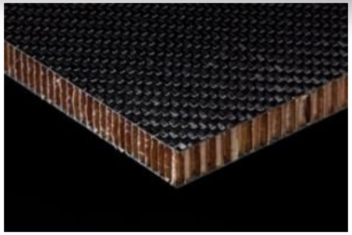
Simon Waite
Senior Expert – Materials

Your safety is our mission.



EASA Sandwich Structure Meeting

Koeln – 18th October 2016



EASA welcomes the opportunity to host….

FAA, Industry, & CMH-17 Disbond/Delamination TG

Attendees (60) representing 30 organisations:

- fixed wing, rotorcraft,
- suppliers, manufactures TCHs, R&D, consultants, regulators

Utah University, DuPont, AD&C Ltd (AFF/HFF), DTU, Fokker, MECAER Av. Gp, FAA, Extra, Leonardo Helicopters, Airbus, Airbus Operations, Airbus Helicopters, Textron, Luxair Airlines, Technic Univ. Dresden, KLM Aircraft, Schuetz Gmbh, Diamond, NASA, Grob Aircraft AG, CAA-Romania, EconCore NV, Turkish Technic, Fraunhofer IMWS, NIAR, Hexcel, RJT Composite Expertise, Institute of Aviation – Poland, EASA

EASA Composite Materials Safety Strategy
Agenda

AGENDA				
08:30	09:00	Introduction	**EASA**	Simon Waite
09:00	09:30	Good Sandwich Design Practice - (redundant design features etc)	**Textron Aviation/CMH-17**	Larry Gintert
09:30	10:00	FAA Composite Plan and Planned Sandwich Structure Advisory Circular (AC)	**FAA**	Melanie Violette
10:00	10:30	Sandwich Structure Design Principle at Airbus	**Airbus**	Chantal Fualdes
10:30	10:45	Break		
		Sandwich Structures - GAG Behaviour and Developing Standards		
10:45	11:15	Face Sheet/Core Disbonding in Sandwich Composite Components: A Road Map to Standardization	**NASA/CMH-17**	Ronald Krueger
11:15	11:35	Round-Robin Mode-I Face/Core Fracture Toughness Characterization of Honeycomb Sandwich Composites using the SCB and DCB-UBM Test Methods	**DTU Mechanical Engineering**	Christian Berggreen
11:35	12:00	Suitability and Robustness of the SCB Fracture Toughness Test for Honeycomb Sandwich with Very Thin Face Sheets		
12:00	12:30	New Sandwich Core Material Developments	**Econcore**	Jochem Pflueg
12:30	13:30	Lunch		

Note: first coffee break 10:20hrs due to fire alarm practice on floors 6 and 7

CS25 thin skin – GAG configurations

EASA Composite Materials Safety Strategy
Agenda

12:30	13:30	Lunch		
		Sandwich Structures – Other configurations and applications, e.g. monococoque and other Critical Load Path Applications		
13:30	14:00	LHD Sandwich Structures Application and Experiences	**Leonardo Helicopters**	Marcello Stefanelli
14:00	14:30	A Damage Tolerance & Fatigue Evaluation Approach for Composite Rotorcraft Airframe Structures	**Airbus Helicopters**	Alexander Honold
14:30	15:00	Sandwich Structures in the AFF World		Marcus Basien
15:00	15:30	PSE including Monocoque Sandwich EASA CM	**EASA**	Simon Waite
15:30	15:45	Break		
15:45	16:15	EASA CM CRD Comments	**EASA/Meeting Attendees**	Simon Waite/Meeting Attendees
16:15	17:15	Feedback/Discussion	**EASA/Meeting Attendees**	Simon Waite/Meeting Attendees
17:15	17:30	Close		

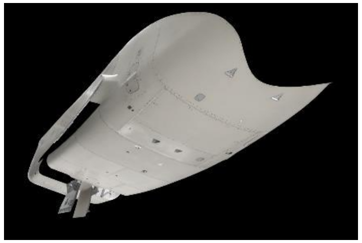
CS27/29 rotorcraft configurations

CS23 GA configurations

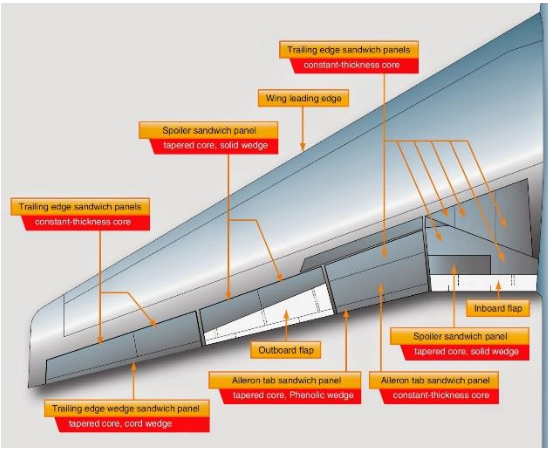
Sandwich Materials/Structures

- established successful use with many sandwich materials…

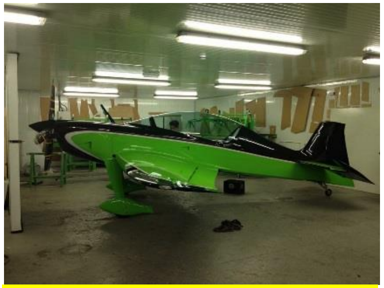
- less critical structures, e.g. fairings, radomes etc



- Primary Structures, e.g. control surfaces



- PSEs….and some monocoque structures



sandwich wing covers and fuselage

sandwich rotor blades and monocoque tail boom and blades

sandwich monocoque fuselage

Sandwich* Materials/Structures

- very broad range of constituent materials, configurations, and applications

Sandwich Constructions (SAE AIR 4844):

Panels composed of a lightweight core material, such as honeycomb, foamed plastic, etc., to which two relatively thin, dense, high-strength or high-stiffness faces or skins are adhered.

- mixed structural functions (skin and core)
- typically bonded (e.g. structurally bonded, co-bonded)

…a structure or a material?

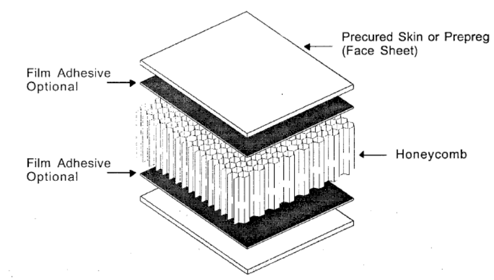


FIGURE 22. SANDWICH PANEL

*Note: identified as 'co-cured' example in AR-96/75 and AC29 2C MG8:

'(7) **COCURE**. The process of curing several different materials in a single step. Examples include …**sandwich structure** or skins with integrally molded fittings.'

This needs review…may not be helpful/appropriate to our discussion….sandwich is carrying primary load through an adhesive between features with different functions, some already cured,… therefore co-bonded/'secondary bonded', would seem to be more appropriate

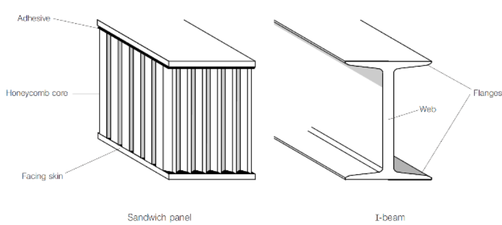


Figure 1 shows the construction of a sandwich panel compared to an I beam.

Sandwich Materials/Structures

- many competing damage modes,
  - some not readily detectable
  - Boundary Conditions important

- some uncertainty wrt damage metrics..

'…it was concluded that residual indentation depth is not a reliable indicator of impact damage; rather, the planar damage size better reflects the residual strength degradation in sandwich panels.'*

*DOT/FAA/AR-02/121 Guidelines for Analysis, Testing, and Non-destructive Inspection of Impact-Damaged Composite Sandwich Structures

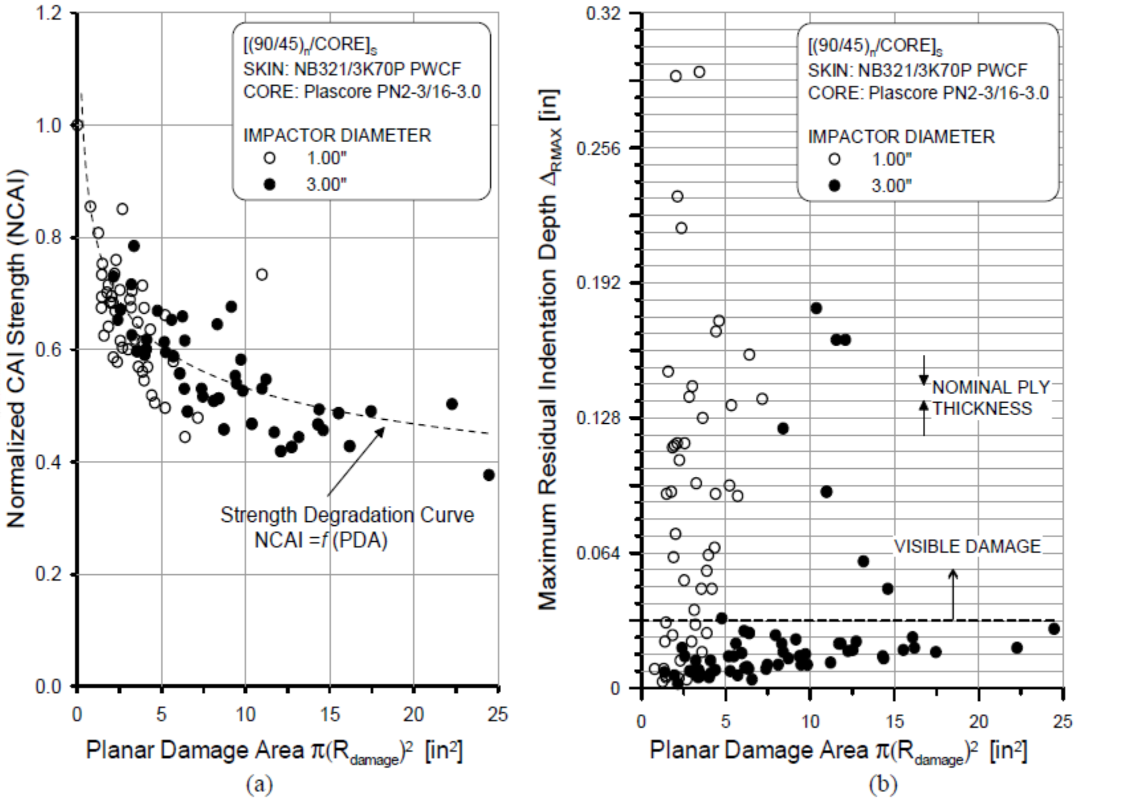
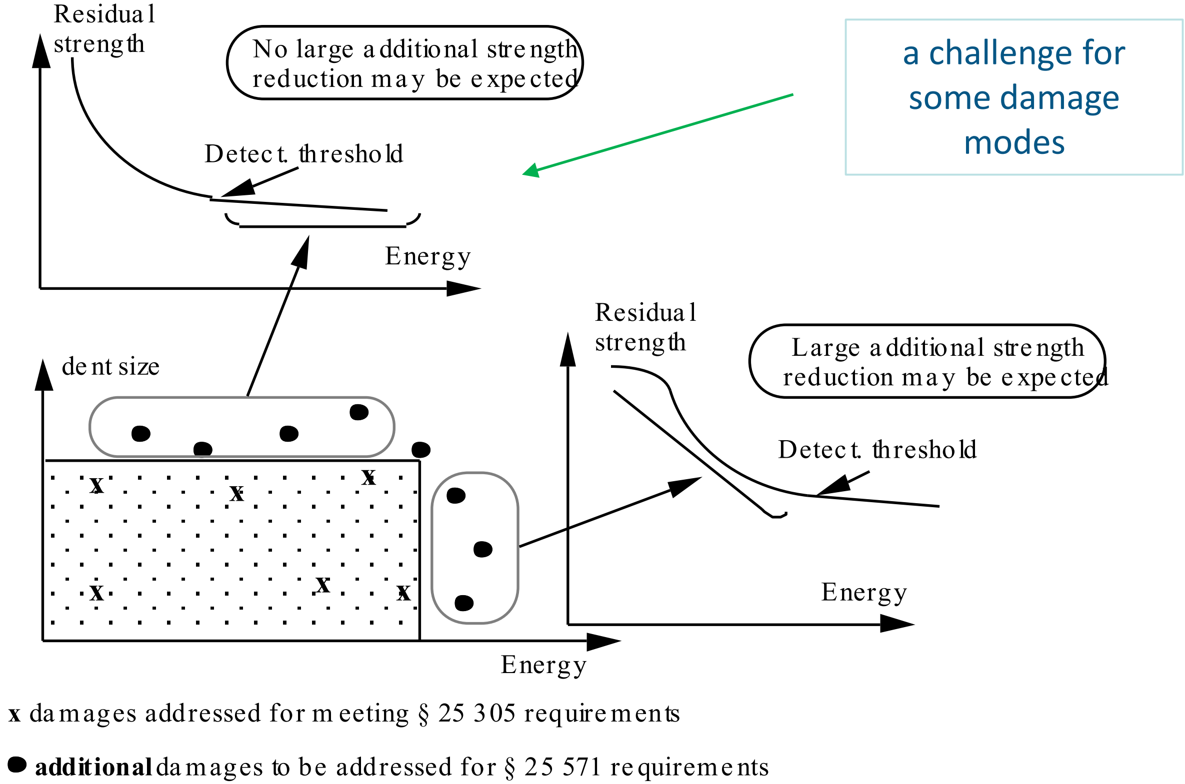


FIGURE 2-10. (a) NORMALIZED RESIDUAL STRENGTH FOR [(90/45)n/CORE]$_s$ (n=1,2,3)* SANDWICH PANELS WITH HONEYCOMB CORE (3/8″ AND 3/4″ THICK) AND (b) VARIATION OF MAXIMUM RESIDUAL INDENTATION DEPTH WITH PLANAR DAMAGE AREA FOR THE SANDWICH PANELS

Sandwich Materials/Structures – Residual Strength

- ideally, detect damage in a configuration which demonstrates no damage growth and has a useful RS (flat part of the curve)



CMH-17 Vol.3 Rev.G Chpt.12

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

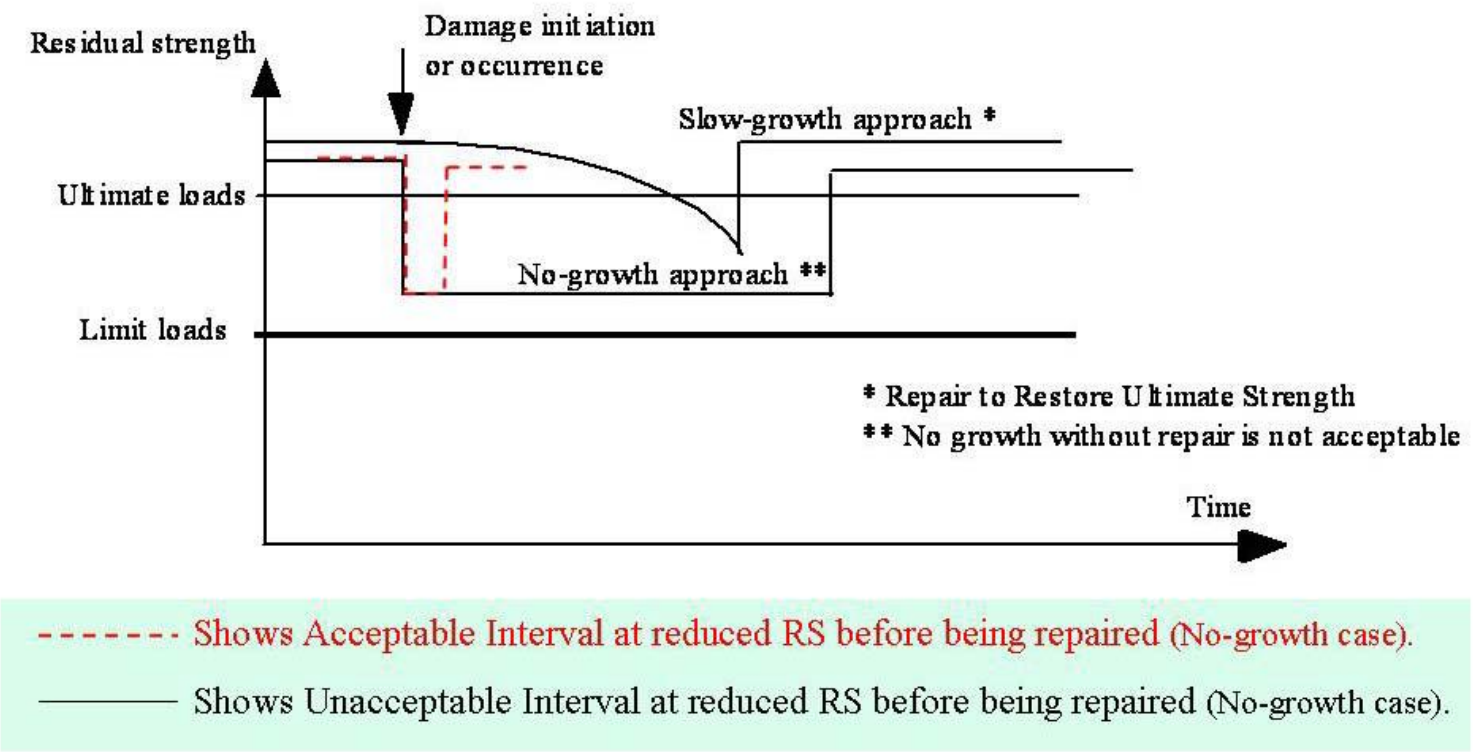


Figure 4 - Schematic diagram of residual strength illustrating that significant accidental damage with “no-growth” should not be left in the structure without repair for a long time.

Example: Key Specification applicable to baseline structure **and repairs**….
(fixed wing and rotorcraft)

CS2x.571: ***Damage-tolerance & fatigue evaluation of structure*** *(ICW CS2x.603 & AMC 20-29)*

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

Note: to be changed to Environmental Damage - ED

'(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 2x.1529'

Does not need to be visual,
…or an inspection
Note: 80-90% of inspections are visual
ref. also CS25.611

need to find, define, and bound damage…

CS29.573: **Damage tolerance and fatigue evaluation of composite rotorcraft structures**:

similar intent other CSs

'(d) Damage Tolerance Evaluation…

(2) The damage tolerance evaluation must include PSEs of the airframe, main and tail rotor drive systems, main and tail rotor blades and hubs, rotor controls, fixed and movable control surfaces, engine and transmission mountings, landing gear, and any other detail design points or parts whose failure or detachment could prevent continued safe flight and landing…

(iv) A Threat Assessment for all structure being evaluated that specifies the locations, types, and sizes of damage, considering fatigue, environmental effects, intrinsic and discrete flaws, and impact or other accidental damage (including the discrete source of the accidental damage) that may occur during manufacture or operation;…'

EASA Composite Materials Safety Strategy

Sandwich Materials - Bonded Structures:

Disbond or delamination:

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

- all of these can occur, but typically not together.....

- most events not significant safety issue*
  applications have not been significant

1 incident 10^6 hrs
1 serious incident 10^8 /10^9 hrs
No fatal accidents
(CAA-UK MOR & fleet data only)

1 serious incident/accident
>10^8 hrs
- EASA database

*variable quality data

- unclear if disbond is cause or witness (either situation suggests poor process - unacceptable)
- **need to improve forensics and taxonomy**

Although difficult to generalise, some configuration/application grouping is possible for investigation, e.g. thin skin sandwich structures (baseline and repairs) subject to Ground-Air-Ground (GAG) cycles …

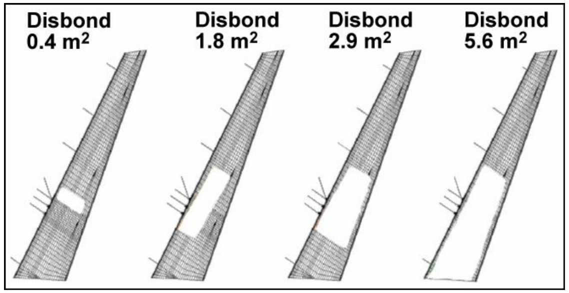
AIRBUS
AN EADS COMPANY

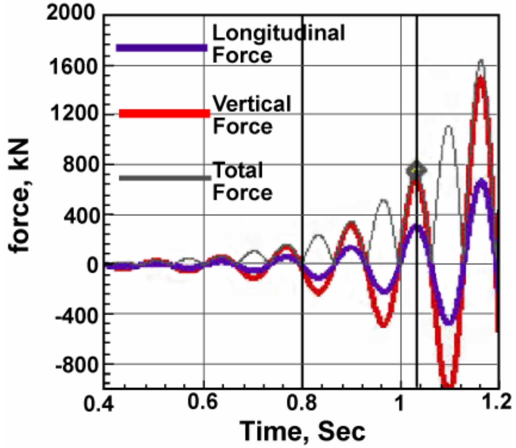
- extensive Airbus work to understand GAG cycle

(Airbus: Roland Thevenin, Ralph Hilgers e.g. presentations CMH-17 26-28/9/11 Delft)

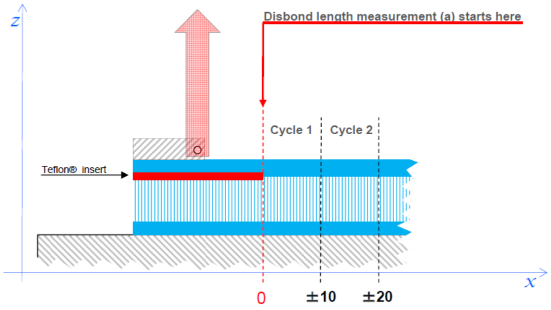
- icw CMH-17 Disbond/Delamination Task Group

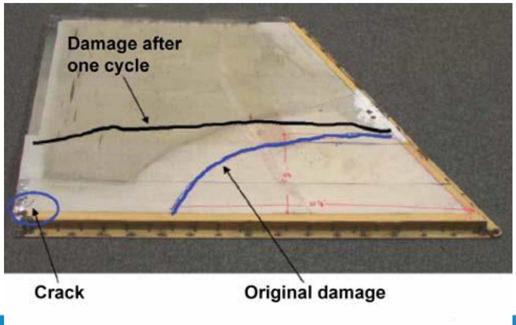
(Airbus: NASA: Ronald Krueger)





Load response – from time domain flutter analysis





typical existing fleet structure configurations

However, some incidents and 'lessons learned' associated with a broader range of material configurations and applications (than thin skin/GAG control surfaces) justify further consideration and possible development of improved guidance material

Discussion points for this meeting include:

/Q/ Is monocoque sandwich structure appropriate for some critical single load path applications, e.g. pressure hull, tail booms etc?

/Q/ If so, then

- what design criteria should be used?
- are back-up features required for critical single load path applications if other mitigating factors are applied:
  - robust F&DT beyond existing multi-load path PSE practice?
  - clear demonstration that the damage modes and RS are understood? (well defined 'flat part of the curve')
- is a developed and standardised version of any existing approach to certification the appropriate way forward?

Example*: To be discussed, and included in 'feedback sheet'

Suggested regulatory approach? *… includes extensive exploration of impact threat…

TASK 1: DAMAGE FORMATION IN SANDWICH STRUCTURES SUBJECTED TO LOW-VELOCITY IMPACT

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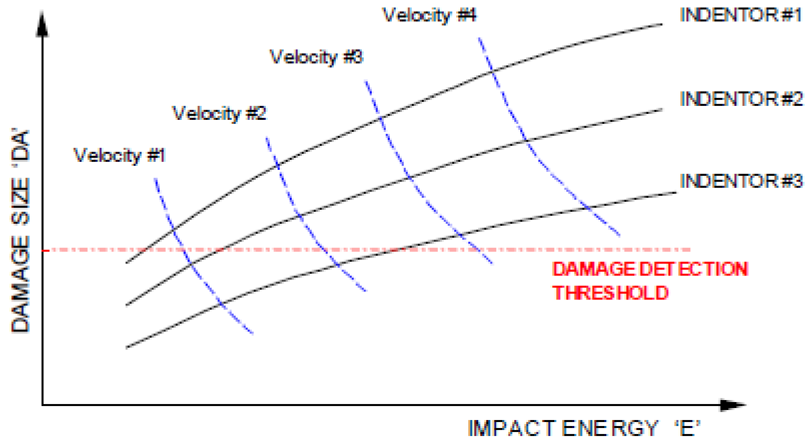

FIGURE 25. TYPICAL PLOTS EXPECTED FROM THE EXPERIMENTAL PROGRAM

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

EASA Composite Materials Safety Strategy

EASA Composite Materials Safety Strategy – related actions:

1/ draft CM for public comment (to be discussed this afternoon)

https://www.easa.europa.eu/documents/public-consultations/proposed-cm-s-010

(comment closed 22/7/16)

2/ R&D – intended to continue development in understanding of the current thin skin GAG issue and also to initiate thoughts for the other configurations:

https://www.easa.europa.eu/the-agency/procurement/calls-for-tender/easa2016hvp14

- related discussion already started…

- CMH-17 Vol.6 (and other references) identifies many potential damage modes

- for some configurations, other than thin skin GAG configurations, organisations have shared 'lessons learned', e.g.

- B. Moitre, A. Marzano (ENAC) - EASA Bonded Structure Meeting June 2013
    - 'lessons learned' regarding monocoque sandwich structures

- A. Engleder (Airbus Helicopters, ex- EC) – CMH-17 Meeting Boston August 2012
    - several rotorcraft configuration specific monocoque sandwich structure damage modes

- D. Wernert (Textron, ex-HBC) – EASA Bonded Structure Meeting June 2013
    - practical robust monocoque sandwich structure design

- can we produce useful generic guidance for such configurations?

Feedback form: Important

- capture missed thoughts (during/following meeting)
- improve future meetings

Can you please complete the feedback form?

- Presentations
- CM Discussion

Please return by 31st November 2016

Thank You!

QUESTIONS?

Support Slides

Sandwich Materials/Structures

- many competing damage modes, some not readily detectable

…difficult to generalise guidance

multiple delaminations

limited external indication

core crushing

CMH-17 Vol.3 Rev. G Chapt.13 Fig.13.2.3.6(c)

CS2x.601*:* General

‘The aeroplane may not have design features or details that experience has shown to be hazardous or unreliable. The suitability of each questionable design detail and part must be established by tests.’

CS 29.602 Critical Parts states for rotorcraft:

'(a) …A critical part is a part, the failure of which could have a catastrophic effect upon the rotorcraft, and for which ***critical characteristics have been identified which must be controlled to ensure the required level of integrity****.*

(b)…Procedures shall be established to define the critical design characteristics, identify processes that affect those characteristics, and identify the design change and process change controls necessary for showing compliance with the quality assurance requirements of Part 21.'

Note: A discussion point…the above text could be interpreted as being applicable to a single load path critical structure of monocoque sandwich construction.

SANDWICH MATERIALS – EXISTING REFERENCE SUMMARY

… some useful messages

(not presented)

useful existing references indicate* (typically thin skin configurations)…

e.g. Damage Resistance:

*'…The study suggested that when both ρ^c/ρ^s and t/L are small, face wrinkling was the primary failure mode. When ρ^c/ρ^s is small and t/L is large, then core shear was the primary failure mode. Face yielding was observed for large values of ρ^c/ρ^s. Hence, the fundamental failure modes for sandwich composites are configuration dependent for the undamaged case. While the given material system may be fairly atypical, **this study indicates that the influence of impact damage on the fundamental failure modes and load for a given sandwich configuration remains to be fully explored**.'*

e.g. Damage Tolerance:

*'… **Numerous experiments have shown that low velocity impact damage in sandwich structures results in significant reductions in the residual strength in tension, compression, shear, and bending** [6]. Typically, the strength after impact is unaffected until the impact energy exceeds a threshold value after which there is a marked reduction from the virgin strength.'*

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

- **many model theories**, largely empirical, e.g.

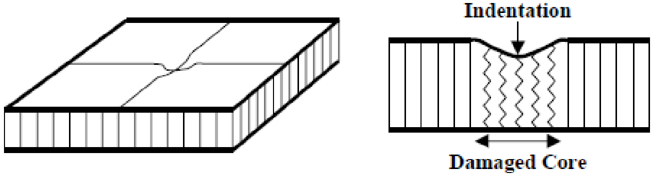

FIGURE 4. MINGUET'S DAMAGE MODEL

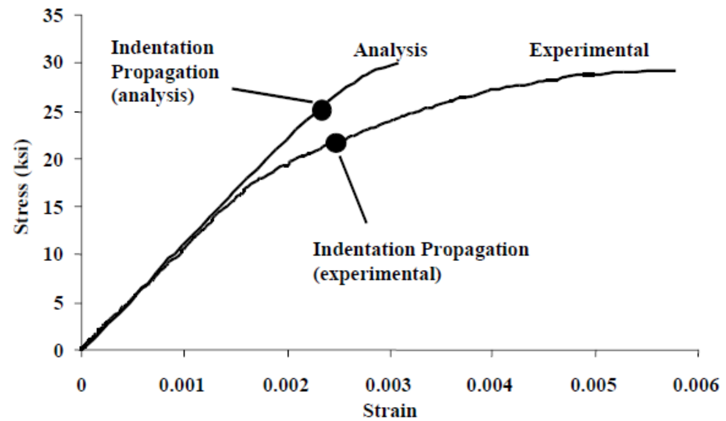

FIGURE 14. INDENTATION PROPAGATION—ANALYSIS VS. EXPERIMENT

' The key concern as demonstrated by Minguet and Kassapoglou is the determination of the point at which the damage due to a low-velocity impact will begin to grow. **A model needs to be developed that combines the indentation aspects of Minguet's model and the reduced stiffness aspects of Kassapoglou's model**. The successful combination of damage characteristics of these two models should result in a model that will accurately predict damage growth. This model will need to accurately model the orthotropic nature of the core including nonlinearity due to damage. With an appropriate database this model will provide a methodology to predict the growth of such damage.'*

- **further work required**…is this valid for other configurations… (damage resistance & tolerance)

* e.g. DOT/FAA/AR-99/91 Damage Tolerance of Composite Sandwich Structures

useful existing references indicate* (typically thin skin configurations)…

e.g. Damage Tolerance and fail-safe:

'…Russell et al. [31] summarized relevant FAA requirements, analysis methodologies, and selected test data for impact damage tolerance and fail safety of composite sandwich panels. …A number of **guidelines for impact damage tolerant design** were presented including:

(1) **sandwich panels should fail initially by facesheet compression** (rather than facesheet buckling) so that the full strength of the composite facesheets can be realized, and

(2) **extensive core damage should not develop at a lower impact level than detectable facesheet damage since this can lead to local facesheet buckling at extremely low panel strain levels.**

A **tear strap methodology** for fail-safe composite sandwich panel design was discussed, along with pertinent residual strength test data for composite sandwich tear strap panels. **Tear straps can be formed by interleaving extra plies of material into composite facesheets at specified spacings and may provide load redistribution capability in the presence of large damage**.'

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

Advanced Composites Technology (ACT) Programme

(composite fuselage – semi-monocoque):

'…tolerance evaluations were performed to ensure adequate structural performance in the ***presence of potential large-scale damage****. The* ***impact damage resistance and post impact load carrying capability*** *of stiffened skin and sandwich structures were investigated… influencing variables included*

Laminates:

'…The experiments indicated that the severity of damage was a strong function of impact variables and variable interactions. ***An inverse relation observed between the damage severity and visibility relating to the impactor geometry suggested that the BVID or similar criteria might be flawed****. More comprehensive material and design-screening approach for composite structures is warranted based on the strong coupling observed between the extrinsic impact variables and the damage characteristics. This study illustrated that* ***the use of a single arbitrary value for an extrinsic variable in a test program may lead to conclusions which may not apply over the full range of potential impact conditions****.'*

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

Advanced Composites Technology (ACT) Programme

(composite fuselage – semi-monocoque):

Sandwich Structure:

'…impact damage resistance and compression after impact (CAI) strengths of sandwich panels representative of minimum-gage fuselage structure with a variety of honeycomb core materials were characterized to aid core material selection …

key experimental results are as follows:

- The impact support type had a minor influence on damage resistance.
- Greater dent depth was observed for impact with rigid supports.
- **Impact with the larger tup resulted in a smaller indentation and greater damage area in almost all the cases.**
- **Core type and density was observed to affect the damage resistance significantly**. The denser (12 lb/ft^3) core sandwich panel sustained less indentation in most cases and less damage area in all cases than the lower density (5 lb/ft^3) core sandwich panel.
- The panels with thicker facesheets sustained smaller indentations and damage over a smaller area than those with thin facesheets for a given energy level.

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

Suggested regulatory approach:

TASK 1: DAMAGE FORMATION IN SANDWICH STRUCTURES SUBJECTED TO LOW-VELOCITY IMPACT

TASK 2: RESIDUAL STRENGTH TESTING OF SANDWICH PANELS.

TASK 3: FLAW GROWTH THRESHOLDS AND DAMAGE EVOLUTION UNDER VARIABLE-AMPLITUDE CYCLIC LOADING.

TASK 4: ANALYTICAL MODEL DEVELOPMENT

TASK 5: FULL-SCALE/COMPONENT TESTING AND VERIFICATION.

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

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Suggested regulatory approach:

TASK 1: DAMAGE FORMATION IN SANDWICH STRUCTURES SUBJECTED TO LOW-VELOCITY IMPACT

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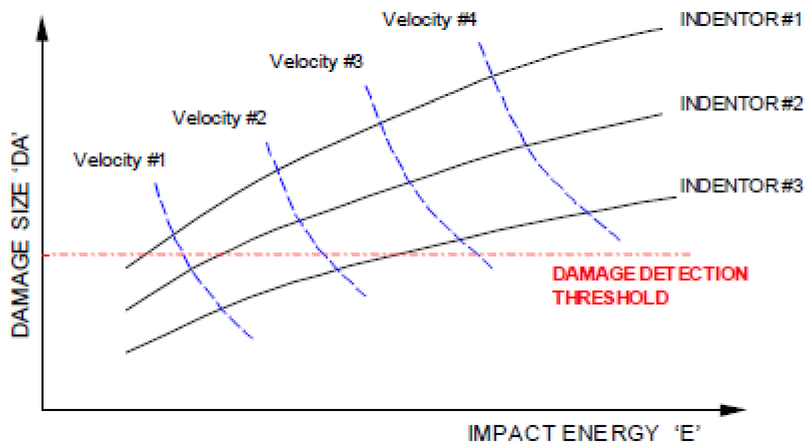


FIGURE 25. TYPICAL PLOTS EXPECTED FROM THE EXPERIMENTAL PROGRAM

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

Suggested regulatory approach:

TASK 2: RESIDUAL STRENGTH TESTING OF SANDWICH PANELS.

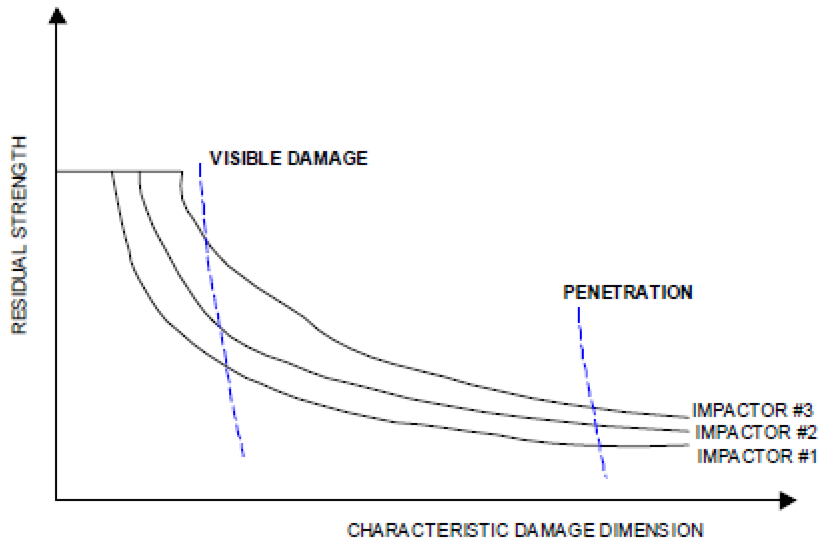


FIGURE 26. TYPICAL PLOT TO BE GENERATED USING THE RESIDUAL STRENGTH DATA

* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

Suggested regulatory approach:

TASK 3: FLAW GROWTH THRESHOLDS AND DAMAGE EVOLUTION UNDER VARIABLE-AMPLITUDE CYCLIC LOADING.

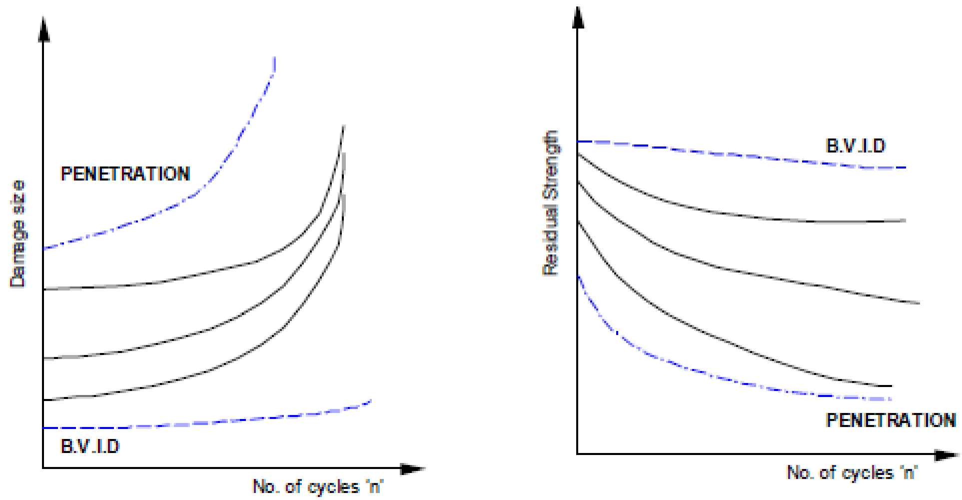


FIGURE 27. TYPICAL DAMAGE GROWTH AND RESIDUAL STRENGTH CHARACTERISTICS FOR SANDWICH PANELS WITH VARIOUS INITIAL FLAW SIZES/TYPES

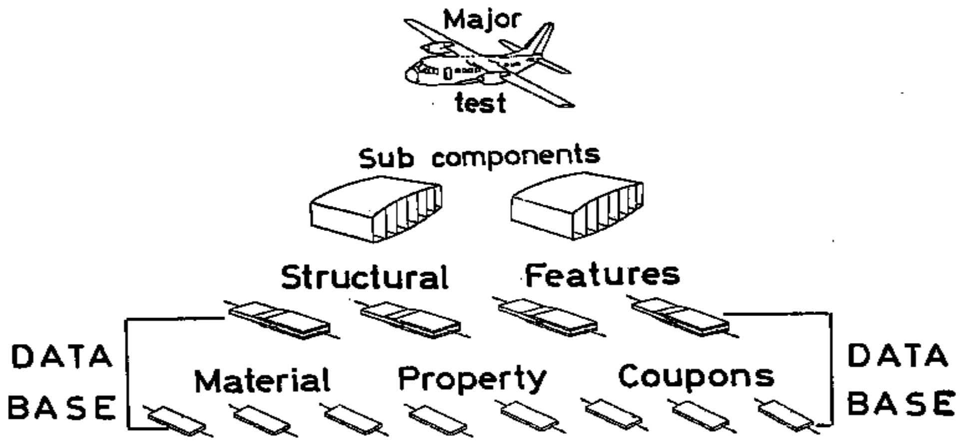
* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

useful existing references indicate* (typically thin skin configurations)…

Suggested regulatory approach:

TASK 4: ANALYTICAL MODEL DEVELOPMENT
TASK 5: FULL-SCALE/COMPONENT TESTING AND VERIFICATION

- appropriate and representative use of test/analysis pyramid



* e.g. DOT/FAA/AR-99/49 Review of Damage Tolerance of Composite Sandwich Airframe Structures

Sandwich Constructions: 2 methods:

- precured/metal skins bonded to core

- skins cured and 'cobonded*' to core
  - lower cure pressure: vent core to atm as positive pressure > 15psi/temp 150f, max 50 psi (wrt 90 psi for normal laminate curing)
    - potential difficult bond line control/skin deformation - weaker bonding
    - use tough adhesive/good fillet
    - can be reinforced with foam

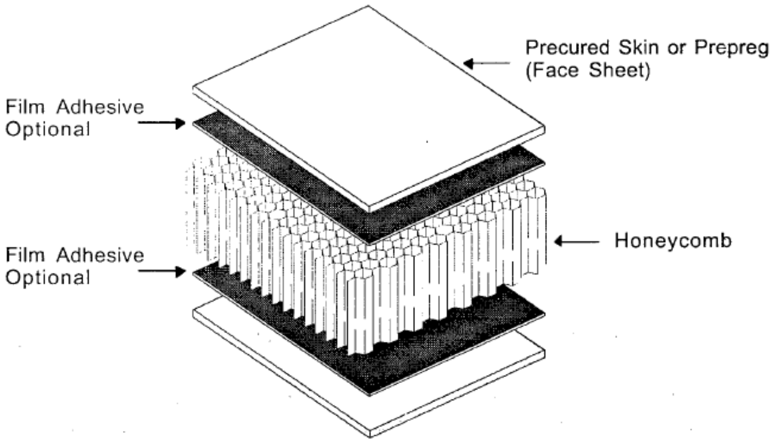


FIGURE 22. SANDWICH PANEL

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(7) **COCURE**. The process of curing several different materials in a single step. Examples include …**sandwich structure** or skins with integrally molded fittings.

….it is carrying primary load through an adhesive between features with different functions, some already cured,… therefore co-bonded/'secondary bonded', not co-cured

EASA* Proposed CM No.: Proposed CM–S-010 Issue 01

Composite Materials - The Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications

Requirements: AMC 20-29 (CS-23 – commuter aircraft, CS-25, CS-27 and CS-29)

* developed icw ENAC (B. Moitre, A. Marzano)

Certification Memo (CM): Terms of Reference

…All interested persons may send their comments, referencing the EASA…

EASA **Certification Memoranda (CM)** clarify the European Aviation Safety Agency’s general course of action on specific certification items. They are **intended to provide guidance on a particular subject and, as non-binding material**, may provide **complementary information** and guidance for compliance demonstration with current standards. Certification Memoranda are provided for information purposes only and **must not be misconstrued as formally adopted Acceptable Means of Compliance (AMC) or as Guidance Material (GM). Certification Memoranda are not intended to introduce new certification requirements or to modify existing certification requirements and do not constitute any legal obligation.**

… **CMs are living documents** into which either additional criteria or additional issues can be incorporated as soon as a need is identified by EASA.

…

Certification Memo (CM): Terms of Reference

Typical use:

1/ standardisation tool, e.g. common acceptable practices not explicitly stated in existing rules and guidance

2/ aid interpolation between existing rules and guidance material

3/ provide complimentary information/emphasise important aspects of existing rules and guidance, e.g. based upon ‘lessons learned’

Composite Materials - The Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications

Para. 1.1 Purpose and Scope:

*'…provides EASA guidance relating to the safe design and use of **monocoque sandwich structures in critical structure applications** ('critical structure' as defined in AMC 20-29), **particularly those structures with single load paths**.*

*…It is recognized that the behaviour of sandwich structures is dependent upon configuration details and that the use of sandwich structures in monocoque critical single load path structure applications tends to be associated with thicker skin and heavier core configurations than is typical of control surface and high lift device designs. Therefore, **this CM does not attempt to address all issues associated with sandwich structures in control surfaces and high lift devices, such as the effect of pressure cycles*'***

* likely subject for future CM, when current work reaches appropriate point

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Para. 3.1 EASA Policy:

*…use of monocoque sandwich structures in **critical structure applications** (‘critical structure’ as defined in AMC 20-29), **particularly those structures with single load paths***

***Para. 3.1.1* Qualification of the manufacturing process**…

emphasising key points based upon ‘lessons learned…’

…manufacturing process to be fully qualified **before starting production**

…demonstrate that the combination of material, tooling, equipment, procedures, and other controls, making up the process, will produce representative parts

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***Para. 3.1.1* Qualification of the manufacturing process**…

…destructive and non-destructive inspection (**NDI**) should be conducted to determine conformity to specified design requirements and **check the suitability of the resulting product by assessing features such as** :

…uniformity of the adhesive fillets between honeycomb core cell wall and skin

…absence of 'telegraphing' effects and waviness on the skins

…distortion of the core cells…potentially critical for highly curved panels unless suitable precautions are taken during fabrication (e.g. core thermal conforming)

…presence in the adhesive of unacceptable levels of porosity or humidity.

…disbonds between core and cells

…weak bonds.

emphasising key points based upon 'lessons learned…'

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emphasising key points based upon 'lessons learned…'

Para. 3.1.2 Process specifications…

…specifications covering **fabrication procedures …**established to ensure that repeatable and reliable structure can be manufactured

…include all necessary instructions to manufacture, inspect, and test the produced parts in order to ensure that they consistently conform

…process specification should…include information required by AC 21-26, paying particular attention to:

…accepting the in-coming material (skin and core) and instructions for its handling and storing conditions.

…instructions for material preparation and curing cycles

…inspection procedures and quality control tests.

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***Para. 3.1.3* Material strength and determination of design allowables**…

… strength properties …probability of structural failure due to material and **process variability be minimised**.

…**because of the peculiarity of the sandwich panel construction, the material properties should be established on specimens fully representative of the panel construction in terms of skin, core material and curing cycle**

…design features such as **transition zones** from solid laminate to core/skin **should also be tested and representative**

emphasising key points based upon 'lessons learned…'

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***Para. 3.1.3* Material strength and determination of design allowables**…

…expected that at least the following static allowables be established according to the statistics required under CS 2X.613:

…adhesive Shear Strength.

…Shear Core Strength (Ribbon and Transverse direction).

…Core Compression Strength.

…Flatwise Strength.

…Flexural Strength.

…Compressive Strength.

…Bearing Strength (for specimen representative of all the panel areas where fasteners are installed and subject to significant bearing stresses.)

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Para. 3.1.3 **Material strength and determination of design allowables**…

…the effect due to humidity uptake, highest and lowest temperature expected in service, manufacturing defects up to limit of acceptability, impact damages should be also considered

…**validity of engineering formula** used to establish analytical design allowables should **always be verified by dedicated experimental activity in order to assess the effects of the manufacturing process** (e.g. curing pressure which is normally limited to the crush core strength) and environmental conditions on the allowable predicted by these formulas.

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Para. 3.1.3 **Material strength and determination of design allowables**…

…it is also expected that **relevant fatigue testing at specimen level, representative of design point** (e.g. fastened joint) and typical panel configuration be performed in order to assess the effects of on the fatigue strength of:

…material/manufacturing process variability

…environmental condition.

…allowable manufacturing defects.

…impact damages.

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Para. 3.1.4 Damage tolerance and residual strength

Para. 3.1.4.1 Threat survey and damage modes

…applicant should clearly demonstrate that a **robust structure** has been produced by showing:

… a thorough damage threat survey …which identifies and defines all threats, including impacts, heat, moisture, etc. and the **potential for interaction of these threats**

…all damage modes have been identified for the configuration when subject to all likely threats, **paying particular attention to all likely damage modes which might not be readily detected.**

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robust structure… possible mitigation for potential undetectable damage modes when no LL back-up feature - TBD

Para. 3.1.4 **Damage tolerance and residual strength**

Para. **3.1.4.1 Threat survey and damage modes**

…impact threats… **testing throughout energy ranges up to readily detectable damage** using a **range of appropriate impactor geometries**, e.g. including sharp impactors and blunt impactors up to diameters agreed with EASA

…it may be appropriate to consider a **range of impactor stiffnesses**, e.g. for hail threat damage, **such that all competing damage modes can be identified**

…**representative boundary conditions** …in the substantiation test campaign.

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Para. 3.1.4 Damage tolerance and residual strength

Para. 3.1.4.1 Threat survey and damage modes

…**all potentially undetectable damage modes** (not only disbonds, but also inner core shear failure etc) …**simulated in testing** (up to appropriate dimensions such that detection becomes possible and the dimensions of such damage have been quantified such that **UL can be maintained up to readily detectable levels**, or to the limits defined by substantiated design back-up features)

…possibility of **interaction between threats and damage should be considered**

…**witness structures***….can be used in service, to trigger airworthiness actions, **provided consistent and conservative correlation can be demonstrated to exist between the indications on the witness structure and the damage**

* in this discussion, meaning in service/part of the structure (not a production coupon)

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Para. 3.1.4 Damage tolerance and residual strength

understand all damage modes – potential to use 'flat part of the curve'?

Para. 3.1.4.2 residual strength

…**unless robust experience*** demonstrated using similar materials and processes in similar configurations at similar strain levels and in similar service environments, …**should be demonstrated to sustain no less than LL capability with obviously detectable damage** for any potentially catastrophic damage modes.**

…potentially catastrophic undetectable damage modes should be identified and addressed for growth up to readily detectable levels for this purpose.

*'grandfathered' technology requires thorough design, production, and supplier review for new products

** 'obviously detectable' means the largest Cat 2 damage which could be missed, not the smallest which might typically be detected

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Para. 3.1.5 Safety Management Systems (SMS)

…appropriate co-ordinated involvement required of material suppliers, the design organisation (TC Holder), production organisations, and those with appropriate continued airworthiness experience throughout the supply, design, development, and certification processes.

…intent …early identification of hazards and the assessment of potential risks relative to the recognised criticalities and design complexities, the manufacturing process, the envisaged production supply chain and environment, particularly with respect to continued airworthiness implications.

increasingly segmented and globalised sub-contractor chain

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Para. 3.1.6 Instructions for Continued Airworthiness (ICA)

emphasising key points based upon 'lessons learned…'

…include **clear instructions to inspect*, both internally and externally**:

…all load paths, e.g. up to load transfer fittings, joints, other significant changes in stiffness and section, for damage following an overload event, e.g. impact, heavy landing, excessive gust etc.,

…**all structure regularly exposed to extreme temperatures**, e.g. local to engine outlets or aircraft used extensively in hot climates, etc.

…. include realistic and substantiated NDI methods

*paying particular attention to:

- repaired structures

- any existing, and potentially related, ICA, e.g. existing ADs, etc.

European Aviation Safety Agency

End slide

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