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

Composite Safety Issues

European Bonded Structure

Industry/Regulator

Working Group Meeting






Koeln

13-14th. June 2013

SUMMARY

CMH-17 Wichita
9-12th. December 2013

(also presented
Hampton Workshop
20-21st November 2013)

S.Waite

Your safety is our mission.

Meeting Purpose: Safe Use of Bonded Structure

Following broadly delivered EASA invitation to European Industry (EASA e-mail 19/2/13) regarding interest in this subject ,the dominant themes/objectives are:

AIRBUS AN EADS COMPANY — Fokker — EUROCOPTER AN EADS COMPANY

- building on existing GAG +ΔP progress (CMH-17 WG, NASA meeting)

- potential for transfer of knowledge between configurations/ applications
- define most useful form of output, e.g. policy, guidelines etc

CMH-17 COMPOSITE MATERIALS HANDBOOK

- identifying future priorities (sandwich and other bonded structures) e.g.

- applicability of NDI to existing fleets/applications
- **GAG cycle without significant ΔP**
- better understanding of disbond initiation and degradation science (better/standardised forensics)
- **define any other industry concerns/priorities for the future**

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Organisations represented (50+ attendees):

Suppliers:

CYTEC/Euro-Composites/DuPont (Kevlar/Nomex)/HEXCEL/Schuetz Gmbh & CO KGAA

Manufacturers:

Agusta Westland/Airbus/Alenia/Boeing/Eurocopter/Extra/Fokker/GKN/ HawkerBeechCraft /Rolls Royce

DOAs:

Aircraft Design and Certification Ltd/Leichtwerk/Lufthansa Technik/UTAS UTC

R&D/Universities:

Element/Florida Univ./German Technische Univ.Dresden/ Inst. Clement Ader/ Inst. for Mekanisk Teknologi Denmark/ Univ. Utah/IWM Fraunhofer/ SERGEM /Composite Expertise and Sultions

Consultants:

Adhesion Associates (M.Davis) /J2R Consulting (J.Rouchon)

Regulators & other Gvt. organisations:

FAA/NASA/CMH-17/ACS-A/DSTO(Australia)/ENAC/EASA/TCCA

* red text – presenting at this meeting

Bonded Structure Meeting – Scope:

Structural Bonding (Critical Parts, PSEs, Primary, Large Secondary):

- **disbond** wrt structural bonding, including co-cured, co-bonded structure and bonded repairs

- sandwich (including **core failure** modes)/monolithic

- metallic/composite/hybrid structures

- all applications, static & dynamic, e.g. large/small fixed wing, rotorcraft, propellers, engines etc

- existing fleet technology/new fleet technology etc

&

- **delamination** (future focus issue?)

Note: recent Airbus/CMH-17 priorities: CS25 sandwich structure, GAG + ΔP, existing fleet structure and repairs

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SUMMARY Of PRESENTATIONS – 13th June

Welcome/Introduction EASA - perspective	EASA	S.Waite
FAA perspective	FAA	L. Ilcewicz
ENAC perspective	ENAC	B.Moitre
CMH-17 Update	NASA/CMH-17	R. Krueger
Root Cause Analysis	Fokker	A. Buitenhuis
BREAK		
Airbus Introduction	AIRBUS	R.Thevenin (R. Hilgers)
Airbus Sandwich GAG + ΔP Experience/Understanding	AIRBUS	R. Thevenin
Sandwich Disbond - NDI Solution	AIRBUS	H.Hicken
LUNCH		
Understanding Sandwich Design Space	HBC	D. Wernert
Core Material - Importance to Failure Mode	Du Pont	L.Richardson
Disbond Forensics	Adhesion Associates	M. Davis
ENAC - Other Design Configs GAG (no ΔP), Understanding Failure Mode	ENAC	B. Moitre
BREAK		
WORKSHOP 1 - Sandwich Structure similarities/differences GAG, GAG + ΔP, CS25, 23, 27, 29 configs		Simon/Larry/ Bruno/Ronald/ Roland/Ralf

SUMMARY Of PRESENTATIONS – 14th June

Recap		EASA
Bonded Repair: SHM or Proof Testing	ACS-A/DSTO Australia	A. Baker (telecom presentation)
Disbond - Fatigue Crack Growth Analysis	Leichtwerk	R. Kickert/ U. Weerts
Significance of Delta P to Disbond Crack Tip Load	IWM/NASA	M. Rinker/ R. Krueger
Skin/Core Disbond - SCB Test Method	Univ. Utah	D. Adams
BREAK		
Future Variable Mix-Mode Sandwich Debond Characterisation Method for Stds Implementation	Univs Denmark & Florida	C.Beergreen
NDI for assessing DT of Aerostructures	Element	S.Sgiannas
Sandwich Implementation - Test Activities	Alenia	A. Lista
LUNCH		
WORKSHOP 2 - Other Bonded Structure Priorities for Industry		Simon/Larry/ Bruno/Ronald/ Roland/Ralf

Meeting Ground Rules:

- **Open discussion** is essential for a productive meeting
  (building upon the Airbus example, R.Thevenin, R.Hilgers)

- Details discussed, not already in the public domain, will not be shared outside the meeting without the contributor agreement

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Surveys: Workshop Preparation Survey and Meeting Survey

Preparation Survey (distributed before the meeting):

Thank You to those who returned it

- intended to **initiate thought** - increase the value gained from the meeting

Meeting Survey (distributed just before the meeting):

Thank You to those who returned it

- **record thoughts /comments** regarding:
  - **Workshops 1 & 2**
  - **Presentations**

- completion by all attendees requested, recognising the different functions represented across the industry

- return to the organisers after the meeting (14th July 2013)

- organisers to use collated data to propose conclusions and objectives to the group, e.g. need for policy, guidance, R&D etc

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Background: Existing Rule/Guidance: AMC 20-29/AC20-107B, via ref. to **CS23.573(a)(5):**

many limitations/caveats

'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) of this section must be determined by analysis, tests, or both. Disbonds of each bonded joint greater than this must be prevented by design features; or

Not to be used to address poor process, poor process is unacceptable, ref. 2x.605

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

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

(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*

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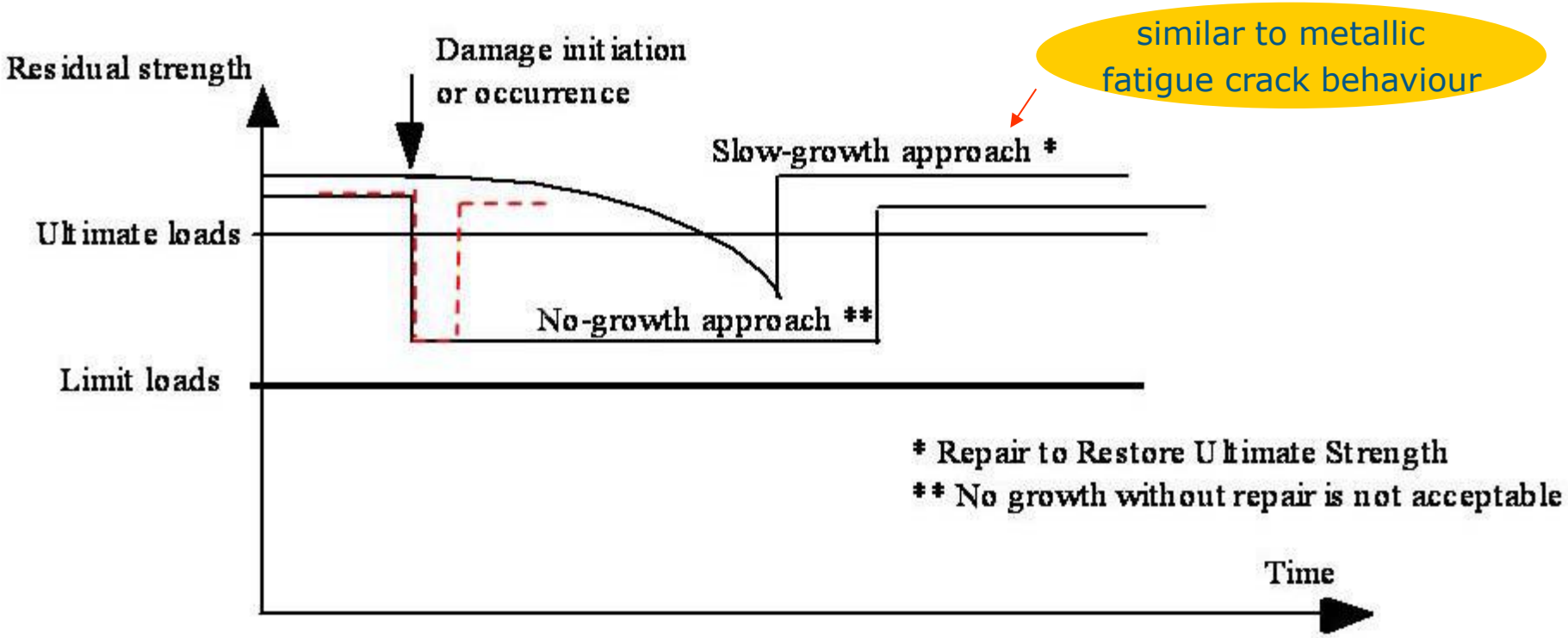

Fig 4 - residual strength illustrating that significant **accidental damage** with "no-growth" should not be left in the structure without repair for a long time.

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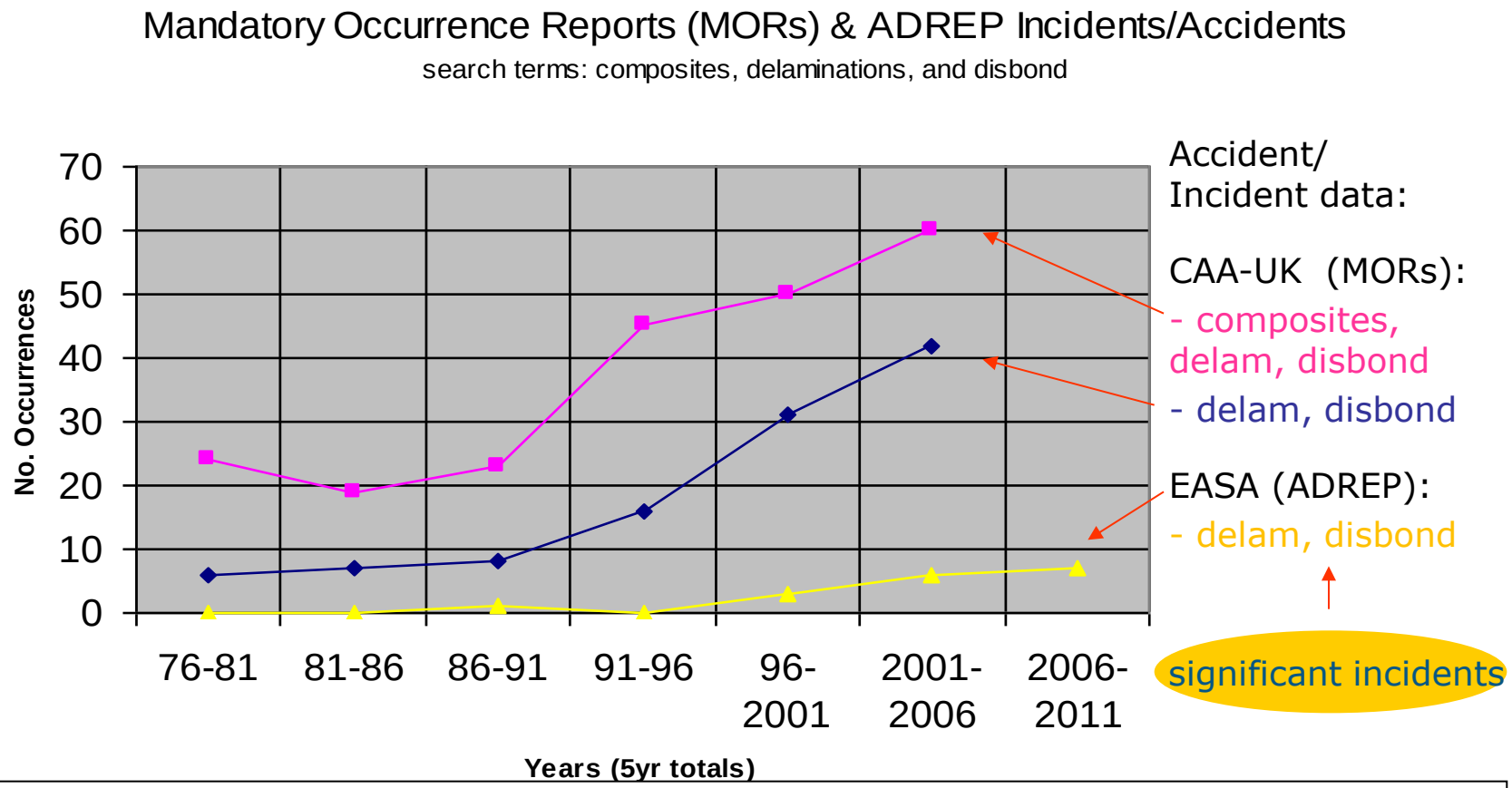
Note: data needs further investigation: unacceptable 'disbond' – cause or witness?



*MOR (UK CAA CAP382) : prevent accidents/incidents…not to attribute blame/liability

Many examples: e.g. AD2010-26-53 …emergency AD – significant failure during acceptance flight test – 7 foot skin disbond from the upper forward wing spar

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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)

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

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)

repair or remanufacture?

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

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more standardisation required?

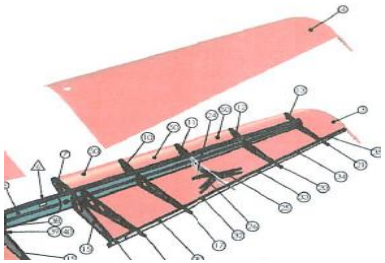
CS 22/23 Bonded Structure – comments:

- extensive use of bonded structure in critical structure applications, e.g. spar/wing cover, bonded glider tail structure repair etc

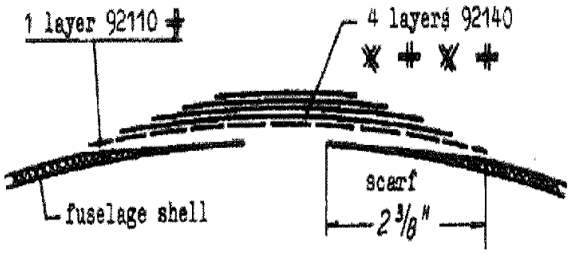
- maintain a generally acceptable level of safety with more limited process control etc, for reasons not conclusively understood, but opinions include:

  - limited point design results in low stresses elsewhere - < weak bond strength levels…

  - some stiff structures e.g. bonded aerobatic spar/wing cover, limit strain contribution to divergent complex damage sequence deformation/stresses…



Bonded Wing/Spar
- no fasteners



Separated Glider Empennage Splice Repair

Wing Rib Disbond
- porosity

Composite Safety Issues

more standardisation required?

CS25 Bonded Structure – comments:

Existing Fleet – extensive use of sandwich structures in Primary and large Secondary Structures – needs attention – NDI?

- evidence of poor repair execution – particularly sandwich structures

- configuration (old)/material degradation issues: Concorde Rudders*/Elevons, AIR TRANSAT Rudder (well described by Airbus)

New Fleet – less sandwich structure, improved configurations, improved use of design rules (>LL capability – one skin failed), more co-cured and co-bonded monolithic structure, e.g. fuselage skin/stringers

* only significant events in CAA-UK database - metallic sandwich structure, first set failure – suspected adhesive degradation, second set failure - machine oil contamination

Composite Safety Issues

more standardisation required?

CS27/29 Bonded Structure – comments:

- extensive use of monolithic and sandwich structure in critical structure applications (more than CS25)
- generally acceptable level of safety maintained
- some 'grandfathered' technologies continue to be used
- some significant disbonding, delamination, and core failure related incidents (sandwich and monolithic, in development and in-service), some events evident in ADs etc
- patchwork approaches to resolving development/certification/ in-service events across the industry

note: some development test failure is useful – aids learning

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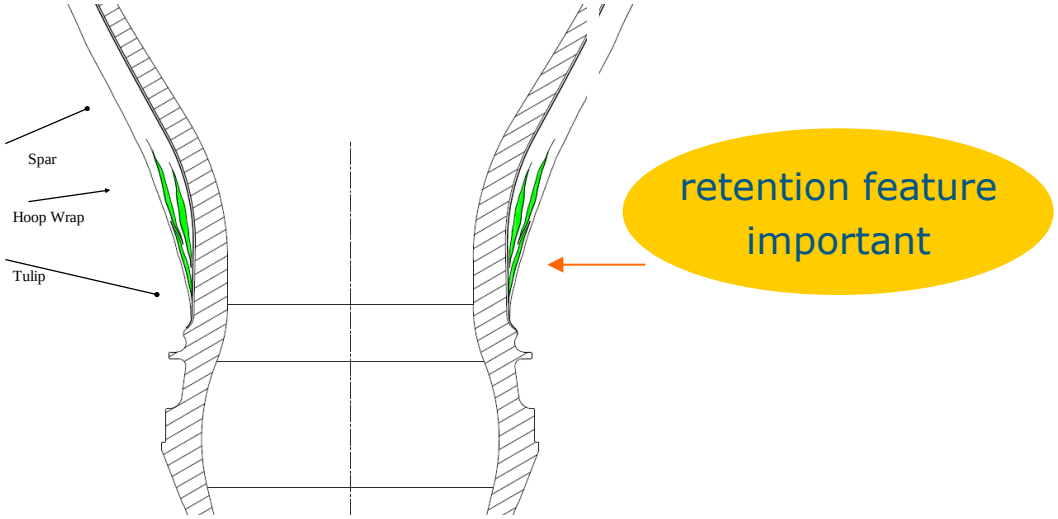
CS-P (propellers) Bonded Structure – comments:

- VARTM cover bonded to metallic tulip root
- disbonded blade retained by ‘back-up’ feature during in-service event (AD issued)
- <u>importance of ‘back-up’ retention feature proved</u>



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Pre-Meeting Conclusion:

Safety requires:

- good practice - design, production, and continued airworthiness
- reliable prediction of Failure Loads, Modes, and Locations

- industry has experienced several serious, and generally lucky, warning incidents, some challenging the requirements above

- industry cannot afford catastrophic bonded structure failure
(concern: undetectable and BVID level disbond, core failure modes, or delamination)

- need to improve current practice, refine design rules, and to standardise

Reminder: CS 2x.601 General

The aeroplane may not have design features or details that experience has shown to be hazardous or unreliable…

Composite Safety Issues

Post Meeting Actions:

1/ Post Presentations on EASA web-site: 28/10/13

http://easa.europa.eu/events/EBSM-June13

2/ Review Presentations Comments Returns – return to presenters

3/ Review Survey Data Returns

4/ Present Survey Summaries at

- Delam/Disbond Workshop (Hampton – November 2013)
- CMH-17 (Wichita - December 2013)

5/ Post Survey and Presentation Summaries on EASA web-site – date TBD

SUMMARY Of SURVEYS

1/ Pre-meeting and Meeting survey return data combined

2/ Attendees (2 days): 57

No. Organisations: 33

No. Pre-meeting Survey Returns: 10

No. Meeting Survey Returns: 6

Any advice regarding future improvement regarding returns welcome!

3/ Reduced summary to be posted on web-site (Excel sheet + word file)

Insert address

SUMMARY Of SURVEYS

Surveys provided for 2 Workshops:

- 13th June: Sandwich Structures
- 14th. June: Other Bonded Structure

Survey Question Structure for each Workshop:

Good experience:

- application (fixed wing/rotorcraft etc)
- structure identification/classification (config, e.g. metallic, composite, geometries etc)
- manufacturing processes
- 'perceived reason for success'

SUMMARY Of SURVEYS

Survey Question Structure for each Workshop continued:

Challenging Experience/Lessons Learned:

- Questions as 'Good Experience' plus:

- 'back-up features' used
- damaging load case
- damage location
- damage modes/sequence
- extent of investigation
- for disbond
  - identified as root cause or witness?
  - how determined?

SUMMARY Of SURVEYS

Survey Question Structure for each Workshop continued:

Challenging Experience/Lessons Learned:

- certification
  - environmental consideration
  - critical failure mode predicted correctly
  - predicted by test or analysis supported by test
- continued airworthiness
  - poor continued airworthiness action/in-action significant to event (e.g. inadequate inspection, poor repair etc)

SUMMARY Of SURVEYS

Good experience – sandwich:

- responses address a range of metallic and non-metallic fixed wing and rotorcraft (airframe/dynamic) applications

reasons for perceived success include:

- o good established process
- o do not use inserts (fixed wing low ΔP – note rotorcraft state ability to include inserts is a benefit (lower/no ΔP wrt fixed wing))
- o only use on vertical surfaces (reduce impact threat)
- o do not use bonded lightning strips (use mesh instead)
- o use ductile adhesive (good fillet/prevents disbond)
- o complete hygrothermal work early in development process
- o ensure adequate thick gage used to address impact, step, and handling loads

SUMMARY Of SURVEYS

Good experience – sandwich continued:

- select material which does not micro-crack or allow moisture ingress
- increased core paperweight and resin weight reduction provides better impact response
- R&D suggests that a 'folded core' might offer an improvements relative to existing core configurations

SUMMARY Of SURVEYS

Good experience – sandwich continued:

Comments included: Generally good experience with co-cured structure… co-cured sandwich structure is not bonded structure - ref. AC29 2C definition

> (11) Cocure. The process of curing several different materials in a single step. Examples include the curing of various compatible resin system pre-pregs, using the same cure cycle, to produce hybrid composite structure or the curing of compatible composite materials and structural adhesives, using the same cure cycle, to produce sandwich structure or skins with integrally molded fittings.

/Q/ Do we need to discuss this as a group?

/Q/ How should we manage co-cured monocoque structure relative to other bonded structure?

SUMMARY Of SURVEYS

Lessons learned – sandwich:

- responses address a range of metallic and non-metallic fixed wing and rotorcraft (airframe/dynamic) applications

- dominate failure mode discussed was disbond at core/skin interface. Also, edge close-out, micro-cracking, delamination, potted hole/insert cracking, shear-crimp, and facesheet wrinkling

- dominate load cases discussed – core pressure, cabin pressure, fatigue, thermal/moisture cycling

'lessons learned' include:

- o need adequate inspections to find moisture (pooled fluid)/moisture damage
- o avoid materials with high moisture up-take
- o avoid unsealed edges, e.g. trimmed aramid fibre, square core, potted details
- o avoid excessive aerodynamic filler (this cracks and takes up moisture)
- o avoid inadequate edge protection/erosion

SUMMARY Of SURVEYS

Lessons learned – sandwich continued:

'lessons learned' include:

- some skin/core combinations have surface prep, machining, low pressure cure, and bond-line porosity issues
- ensure adequate thermal insulation of panels exposed to temperature
- acoustic panels can suffer moisture ingress through perforations
- although quality cannot be inspected into the part, NDI at the end of manufacture is considered to be important
- thorough NDI is required, particularly around details, to avoid missing faults which may be within the NDI capability, e.g. inclusions masked by fittings etc
- ensure appropriate selection of Nomex and Kevlar core/skin combinations for interior or external use
- painting can provide significant protection against moisture ingress
- drain paths are important
- R&D suggests use of 'folded core' might offer drainage benefits

SUMMARY Of SURVEYS

Good experience – other bonded structure:

- responses address a range of metallic and non-metallic fixed wing and rotorcraft (airframe/dynamic) applications

reasons for perceived success include

- rigorous process and development work
- tough matrix
- bond stiffening elements
- broad bond area allowing bolted repair
- disbond arrest features
- realistic impact threat consideration
- bonding and riveting combination considered practical
- moderate loads on bond-lines

SUMMARY Of SURVEYS

Good experience – other bonded structure continued:

- low peel stresses
- mechanical fasteners at high peel stress locations
- bond-line protection
- wide flange
- some manufacturers have shown outstanding durability of production metal-metal bonding
- R&D: lamb-waves are showing good advanced warning of non-visible scarf joint disbond failures

SUMMARY Of SURVEYS

Lessons learned – other bonded structure:

- responses address a range of metallic and non-metallic fixed wing and rotorcraft (airframe/dynamic) applications

- dominate failure mode discussed was disbond, including Mode I scab patch issues

- no dominant load case discussed – various modes, static and fatigue

'lessons learned' include:

- surface preparation
- compatibility
- consistency of adhesive mix
- bond-line porosity for non-autoclave bonds

SUMMARY Of SURVEYS

Lessons learned – other bonded structure continued:

'lessons learned' include:

- poor bond experienced due to non-agitation of primer (metal bond – change from CAA to PAA (historic issue))

- although the classic consideration of a disbonded stringer may be assumed, note that local detail fitting disbond may result in significant load redistribution at joints (and may be more difficult to detect)

SUMMARY Of PRESENTATIONS

- presentations generally well received

specific comments to be sent to presenters

most interest in:

o M. Davis disbond presentation

o HBC sandwich design presentation

o ENAC tailboom presentation (design, production, continued airworthiness interaction important)

o Leichtwerk crack modelling, and its relationship to Ronald and Martin's work

o the Airbus presentations – need for more information regarding NDI

o need for better event data, taxonomy, and stronger emphasis on design, production, continued airworthiness interaction important

some concern expressed regarding:

o focus/appropriateness of presentations (However, this was expected because this meeting was partly intended to allow a broad response from industry)

o the relevance of some of the more academic presentations

SUMMARY Of Comments to Regulators

- the need for guidelines regarding acceptable alternative load paths was expressed (I understand wrt sandwich residual strength and monocoque single load paths)
- failure analysis of incidents has not matured
- there may be some value in comparing core behaviour history in structures (foam could be better than some honeycombs?)
- need for a composite-composite, and possibly a composite-metallic, wedge test
- the next meeting should be more focused and allow more discussion/workshop time
- need to further develop open discussion
- airframe builders do not like (even are not allowed) to talk about structural problems
- 'We should talk about the unexpected things…not mentioned in our standards and how we cope with the ever ongoing race to reduce weight without loosing structural integrity over the lifetime of new generation aircrafts, this includes serviceability and repairs.'

EASA – Preliminary Conclusions

Based upon a summary of written and verbal comments received regarding the surveys and presentations, there is a need for:

- improve forensics and taxonomy of incidents – improve data upon which we base decisions
- clarification regarding the definition of bonded structure, and the implications of this to applications
- reliable bond integrity/durability testing, e.g. composite-composite, and possibly a composite-metallic, wedge
- improve bonded structure training
- significant improvement regarding integrated design, production, and continued airworthiness – particularly for critical sandwich structures – Safety Management Systems
- need to develop better understanding of GAG without ΔP disbond, e.g. GAG + Δ T, and other non-visible potentially catastrophic bonded structure failure modes. Industry help needed.

Safety Management Systems

Many thanks for your support and open discussion
Further comments and opinions welcome!