Composite Safety Issues

Industry/Regulator WG

Damage Tolerance and Maintenance Workshop

Montreal
September 2015

S.Waite, EASA, Certification Directorate

Your safety is our mission.
Composite Safety Issues

Damage Tolerance and Maintenance

15th Sept:

1/ **EASA Future/Developing activities:**
   - **R&D**
     - Sandwich Disbond – Airbus/NASA/CMH-17 (R. Hilgers etc)
     - Ageing Composites – EASA – EU
     - HEWABI continuation – EASA - EU
   - **CMs** (Certification Memos)/**Generic CRIs** (Certification Review Items)
     - Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications
     - non-TCH antenna Mods
     - composite seats

2/ **CM – BRSL** (Bonded Repair Size Limits) – Progress (ref. L. Cheng)

16th Sept:

3/ **EASA – HEWABI** (EASA - CODAMEIN phase III completion)
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EASA Developing R&D:

1/ Sandwich Disbond – Airbus*/NASA/CMH-17

Support completion of tasks forming part of the established Airbus/NASA/CMH-17 sandwich disbond project...

- CS25 configurations – Ground–Air–Ground (GAG)
- consider potential to develop for other configurations, e.g. rotorcraft

* Ralf Hilgers, and Roland Thevenin
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**EASA R&D:**

**European Honeycomb Sandwich Disbond Characterisation (EHSDC)**

Airbus Operations GmbH / Project Lead
Airbus Helicopter, Donauwörth
DTU – Technical University of Denmark
Fraunhofer Institute for Mechanics of Materials IWM
DuPont International Operations Sàrl, Geneva
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**EASA R&D: EHSDC**

- Task overview

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**NASA/NIAR Coordination**

- NASA
- Airbus
- Utah
- DuPont
- NIAR
- FhG
- DTU
- FAU
- GaTech

**SCB draft standard**

- ★
- ★

**Coupon manufacturing**

- ★

**Coupon testing**

- ★
- ★
- ★
- ★

**Mixed-mode standards**

- ★

**Analysis development**

- ★
- ★
- ★
- ★
- ★
**Composite Safety Issues**

**EASA Developing R&D:**

1/ Sandwich Disbond – Airbus/NASA/CMH-17

**Progress:**

3yrs 3x Euro 100k to support existing Airbus led activity
- status: passed 1st internal EASA filter (outcome TBD - start 2016 TBD)
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EASA Developing R&D:

2/ Ageing Composites – EASA – EU

- Many extended composite applications entering service,
  - is there an ageing composite structure issue?

- Benchmark where we are and what might need to be done...
EASA R&D:

Ageing Composites

Bonded Joints and Structures - Technical Issues and Certification Considerations; PS-ACE100-2005-10038 Page 21:

It is impractical to directly evaluate the long-term durability of bonded structures, which includes real-time environmental exposure, in large-scale tests before certification. As discussed in Sections 3.1 and 3.2, aggressive environments and extreme loading (for example, cleavage forces) are used in smaller scale tests to expose bonded interfaces to conditions, which are known to accelerate degradation mechanisms for weak or contaminated bonds. Although this approach helps ensure good bonding processes, the long-term durability of bonded production aircraft structure is validated by service experience. As a result, close ties between the service and production departments of a manufacturer are essential.

Uncertainty supported by literature (see back-up slides):
- engineering property variation resulting from:
  - prolonged exposure to sub-Tg temperatures
  - thermal cycling at different sub-Tg temperatures
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EASA R&D: issues of interest include:

- reversed engineering assumptions wrt metallic experience
  - impact threat survey

- degradation mechanisms
  - artificial v real ageing

- hybrid structure
  - thermal aspects
    (real v cert assumptions)

- interaction multiple BVID, degradation, repair interaction
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EASA R&D: issues of interest include:

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*, will be avoided throughout the *operational life of the aeroplane...*’ (also see MSG3, e.g. para. 2.4.3)

**Current Situation:** composite threat likely to be AD/ED* (metal experience - Fatigue/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

Note: AMC 20-20 not called in 25.571, and is metal based
EASA R&D: issues of interest include:

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

Reminder:

The PSE definition – need for improvement...

‘2.2 Identification of Principal Structural Elements. Principal structural elements are those which contribute significantly to carrying flight, ground, and pressurisation loads, and whose failure could result in catastrophic failure of the aeroplane.’

- does not refer specifically to fatigue or metallic structures...
- could be improved (e.g. system structures included etc)
- seats?
- part departing aircraft?
Increasing efforts to understand aging composites include, e.g. FAA, NIAR, and work by A. Baker*, M. Davies**

**Aging Composites:**
- investigation of two aircraft structures, a decommissioned composite Boeing 737 stabilizer that had a commercial service history of 18 years and a Beechcraft Starship with 12 years of service…sub-tasks to understand the aging mechanisms of the structures.

* proposed approaches to detect degradation in service
** developing better understanding of disbond mechanisms

Conclusions: Little evidence of degradation. However, structures not representative of new exposed structure and impact threat environment, e.g. CS25 fuselage
EASA R&D: Objectives:

Generic:

- *Identify specific potential ageing composite aircraft structure issues (baseline structure (including bonded joints) and repairs) in existing (and developing) fleets in order to:*

  - provide a comprehensive reference point for EASA in developing international industry and regulatory ageing composite discussions, e.g. regarding the need for fleet leader/fleet sampling activities* beyond existing derived maintenance assumptions, e.g. level of visual inspection in current use etc (e.g. chemistry)

  - define potential EASA and/or EU R&D projects addressing ageing composite structures

* technology application changes develop quicker than ability to develop extensive ‘service experience’

(similarly argument could apply to Additive Technology)
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**EASA R&D: Objectives:**

**Specific objectives** (also noting the existing long established use of composite structures in critical structure applications in the small fixed wing and the rotorcraft industries):

- Literature review of issues identified in this proposal

- Literature review to identify any potential ageing composite issues additional to those already identified in this proposal

- Identify likely damage mechanisms

- Identify inspection/detection methods available which will allow detection of such mechanisms (e.g. visual inspection, structure cut-up, chemical sampling, the use of witness patches etc)

- Identify appropriate potential content for fleet leader/fleet sampling activities
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Objectives:

- Identify other appropriate potential inspection content, e.g. additional to existing MRB activities etc

- Identify potential R&D activities, e.g. identify need for appropriate ‘boneyard’ structure cut-ups, applying repairs to existing ageing structures etc

Measurable: Report to be issued addressing the points above

Attainable: Possible if EASA quickly identifies key TCH and material manufacturer contributors.
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**EASA Developing R&D:**

2/ Ageing Composites – EASA – EU

**Progress:**
- Phase I - 1 yrs  Euro 50-100k scope issue/define activity for Phase II
- Phase II - ? yrs Euro ??.
- status: passed 1st internal EASA filter, submitted to EU (2016+ TBD)
EASA Developing R&D:

3/ HEWABI continuation – EASA - EU

Continue the EASA CODAMEIN* work  (discuss tomorrow)

- High Energy Wide Area Blunt Impact work run in parallel with FAA project (Hyonny Kim)

- Hyonny Kim: Composite structure (composite skins, stringers, frames)
- Bishop: Hybrid structure (composite skins, stringers, metallic frames)

* Composite Damage Metrics and Inspection
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EASA R&D:
Composite Damage Metrics and Inspection (CODAMEIN IV)

Current work (5 frame structure):
- improved (increased) BC identified (barrel + floors)
- test rig limitation (only 18% of planned stiffness achieved)
- marginal external damage indication
- address BC issue & higher pyramid structure

*to be discussed tomorrow*
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EASA Developing R&D:

3/ HEWABI continuation – EASA - EU

Progress:
- Phase IV – 1-3 yrs: Euro ? move up test/analysis pyramid (continue parallel work with H. Kim)
- status: passed 1st internal EASA filter, submitted to EU (2016+ TBD)
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EASA Developing CMs/CRIs:

‘The Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications’
Composite Safety Issues

EASA Developing **CM: The Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications**

**Background:**

- **rotorcraft tail boom collapse** (primary load path monocoque sandwich*)
  - Cat 5 event, repaired, potentially catastrophic failure mode not detected (design, production, and CAW issues)

- **various poor repairs/’remanufacture’ and Transat etc...**
  (less critical structure, config differences wrt rotorcraft noted)

- **various failure mode, load, location development ‘surprises’**

**Is it appropriate to use such a design concept for primary critical load path structure, particularly when undetectable and potentially catastrophic damage modes may exist?**

*definition issues
- Is ‘green’ skin cured on core really a co-cured structure?
- Is such a configuration a bonded structure?
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EASA Developing **CM: The Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications**

**CM intent** (for primary load path critical monocoque sandwich structure):

- ensure robust structure design

- explore potential for many damage modes e.g.
  - apply impact through range of impactor geometry configurations and energies, particularly if LL capability cannot be shown with extensive undetectable damage to one skin and/or core and/or the skin-core interface (ref. HBC development experience, e.g. hail threat etc)

- increase attention paid to such structure - teamwork issues (POA, DOA, CAW, interaction - OSD, SMS activities)
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EASA Developing Cert Memos:

‘The Safe Design and Use of Monocoque Sandwich Structures in Critical Structure Applications’

Progress:
- intent and draft text agreed with ENAC Italy (A. Marzano, B. Moitre)
- evolving draft CM applied as CRI on several rotorcraft projects
EASA Developing CM:

Non-TCH Antenna Mods (small and large)
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**EASA concern:** Non-TCH mods, particularly antenna mods and other pressure hull penetration mods

- Metal History: relatively simple, available data allows some scope of non-TCH activity – reality is that it has worked for many decades

- Composites: no shared allowable data available, e.g. open hole, closed hole etc
  - non-penetration areas – holes introduce new potential structure configuration damage modes
  - penetration areas – hole size, geometry, and separation data not readily available
  - local reinforcement strain reduction proposals transfer loads elsewhere

**Current TCH position** (as EASA understands):

- some structural provisions in airframes (inevitably user industry comes up with other needs)
- completion centres/TCH support (cost - level of support?)
- individual applicant contracts with TCHs (cost – timescale issues?)
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**EASA concern:** Non-TCH mods, particularly antenna mods and other pressure hull penetration mods

Regulator position:

- reality - increasing applications for mods
- user industry expects to be able to complete similar activities in composite airframes as metallic airframes, but does not have data*
- TCHs need to be resourced to support this relative to necessary user timescales and costs
- EASA current position – direct applicants to TCH
- EASA suggests need for more accessible guidance for the benefit of all concerned

* See ‘A Conceptual Framework for Practical Progressive Damage Analysis of Stiffened Composite Aircraft Structure with Large Notches Subjected to Combined Loading’ – Tom Walker CMH-17, SLC March 2015, for a summary of the ‘large notch’ challenge
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EASA Developing AOB:

Composite Seats: static and dynamic seats  (pre and post JAR25 amdt.13)
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EASA Developing AOB:

Composite Seats (static and dynamic):

- many applicants
- many configurations
- need to standardise (SAE WG formed)
- intent of appropriate sections of AMC 20-29/AC 20-107B applied as supplement to ETSO
  - Manufacturing issues
  - DT - potential for damage to exist, include damage (sharp and blunt impact, disbonded critical joint in test etc)
  - appropriate test/analysis pyramid
  - Post dynamic test application of load (locate hidden damage)
  - continued airworthiness (includes inspection tasks and fleet leader expectations)
  - ‘equivalence’– strength and stiffness (pulse*)

*damaging pulses 20-40g (function of peak and duration).
- seat must be strong enough to not fail < 9g (static), or < 16g (dynamic), but not too strong/stiff resulting in excessive pulse
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EASA Developing AOB:

Composite Seats current Situation:

- first ETSO/TSO issued - pre-JAR 25 chg 13*, ‘static seat’

- SAE WG activity – (lead by Allan Abramowitz – FAA)
  - seems industry does not wish to share at standardisation level - regulators may need to initially address this alone

*Note: NPA 2013-20 ‘Seat crashworthiness improvement on large aeroplanes — Dynamic testing 16g’ in progress:

‘(Part 26)... to add additional airworthiness requirements and specifications for operations in order to make the above CS 25.562 specifications applicable also to newly produced aircraft of already approved type."

* Note: crash strain rates typically below level of ‘typical’ significant property change (approaching ballistic), so similar failure mode might be expected (ref. WSU strain rate work etc)
EASA - 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*
  (most applications have not been significant)

*variable quality data

- unclear if disbond is cause or witness (either situation suggests poor process)

- need to improve forensics and taxonomy

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

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1 serious incident/accident
$>10^8$ hrs
- EASA database
Composite Safety Issues

EASA Bonded Repair Size Limits CM - Update:

- Policy text in agreement with FAA PS (and previous WG agreement)
- status:

- Minor outstanding issue: European industry requested visibility of criteria allowing deviation from LL limitation, e.g. when TCH has adequate control/confidence/experience to show that the repair facility can achieve more (approaching production repair capability?)

- published 11th September 2015

Composite Safety Issues

Further point: MRB (Maintenance Review Board) v ALS

Recent Activity Example: Discussed briefly with FAA, Airbus, Boeing at CMH-17 meeting (August 2014).

Level Playing Field*:?

- What differences in design and substantiation justify such a difference?
- What differences in regulatory practice justify such a difference?
- What level and frequency of inspection is appropriate for ageing composite fleet?

*Note: Too many interfaces between and within TCH/Regulators

- MRB Industry/EASA (MRBIE) – link Design Organisation Approval process to MRB activities (within organisations and EASA)
  - process trial 4 TCHs engaged
- function wrt Bilateral Agreements - TBD

needs standardisation?
Questions?
EASA R&D:

Composite Safety Issues

Composite Damage Metrics and Inspection (CODAMEIN – Phase III completion)

See Bishop Phase III completion presentations
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EASA R&D:

Composite Damage Metrics and Inspection (CODAMEIN – Phase III completion)

See Phase III closing presentations

Conclusions/recommendations:

1/ significant internal damage produced with limited external damage being evident

notes:

- although improved stiffer BCs defined (included floor structure etc), test equipment only permitted 18% of intended rotational stiffness to be achieved

- although project aimed to test ‘worst case’ scenario, the actual externally evident damage was the result of contact between the skin and a local bolt attaching the rubber bumper to the impactor (suggests difficulty trying to intentionally produce undetectable damage). However, significant shear tie damage resulted from lower level load case – no external damage
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EASA R&D:

-Externally visible crack
  - Bumper attach
  - Fastener contact

-Extensive delamination
  - Stringer feet
  - Shear ties
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EASA R&D:

2/ evolved modelling from Phase I and II (+ working with H.Kim) allowed reasonable prediction (approx. 7% ) of initial internal damage initiation

Model: Non-linear, explicit, dynamic (ABAQUS)
  - continuum shell (was shell)
  - cohesive elements (to address delamination, e.g. between co-cured elements, and within shear ties (only 2 layer))
  - failure criteria added (Hashin)
  - fasteners represented

- damage much as Phase I and II, shear tie failures, followed by frame bending
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**EASA R&D:**

Hypothetical Summary wrt Cert requirements:

‘reverse engineering’ suggests impacts > 140J* occur < 10-9 flt/hr it does happen, but is it always reported (ground event)? – hence need for the developing policy.

Summarising Phases I, II, III

1\textsuperscript{st} internal damage (shear tie) 946J
multiple shear tie and stringer feet delam damage 2000J**
(+ some frame bending)

** externally visible (only due to local fastener contact)

Can this be managed as an extended Cat 2 local to door cut-outs?
### Composite Safety Issues

#### Load Level - Detectable Damage

<table>
<thead>
<tr>
<th>Structure Stiffness</th>
<th>Threshold</th>
<th>Test Load Level</th>
<th>Energy Plateau</th>
<th>Detectable Damage</th>
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<tbody>
<tr>
<td>Low</td>
<td>1</td>
<td>20-27 kN</td>
<td>700 J</td>
<td>No failure Bumper fully compressed, Undetectable damage</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
<td>39-46 kN</td>
<td>1000 J</td>
<td>Local Shear Tie unfolding, Undetectable damage</td>
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<tr>
<td>Medium</td>
<td>2</td>
<td>57-66 kN</td>
<td>1500 J</td>
<td>Local Shear Tie damage, Undetectable damage*</td>
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<tr>
<td>Medium</td>
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<td>66-83 kN</td>
<td>2000 J</td>
<td>All Shear Tie damage, Undetectable damage*</td>
</tr>
<tr>
<td>High</td>
<td>3</td>
<td>&gt; 83 kN</td>
<td>&gt;2000 J</td>
<td>Shear Tie, Frame permanent deformation, Detectable damage</td>
</tr>
</tbody>
</table>

* Undetectable damage from Outside, Detectable damage Inside when incident reported
Composite Safety Issues

Possible MoC:

Further to a basic robust design strategy...

1/ Explicitly require ‘fail-safe’ design in high threat areas

and/or

2/ Extended analysis, + limited additional ‘book case’ reference testing:

- identify structure at ‘high’ risk of HEWABI
- select ‘typical’ high risk configuration(s)
- analysis impact with representative impact energy/impactor which might result in no external damage (1000-2000J/rubber bumper)
- validate model with representative impact energy/impactor (1000-2000J/rubber bumper) ‘book case’ test which is expected to exercise the dominant damage modes
- ensure damage modes and extents supported by Cat 2/3 work (residual strength/substantiated inspection intervals)
HEWABI – evolving related regulations:

Further to AMC 20-29/AC 20-107B:

‘Pilots, ramp maintenance and other operations personnel that service aircraft should be trained to immediately report anomalous ramp incidents and flight events that may potentially cause serious damage to composite aircraft structures’

EASA Basic Regulation EC No 216/2008 Annex II says *(draft amendment)*:

D. Ground handling services:

*(b) the provider shall ensure that movements of vehicles and persons in the movement area and other operational areas are coordinated with movements of aircraft in order to avoid collisions and damage to aircraft*:
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HEWABI – evolving related regulations:

New Rules/AMC: Improve operating environment and training, e.g.

ADR.OPS.B.025 Operation of vehicles:
‘The aerodrome operator shall establish and implement procedures for the training, assessment and authorisation of all drivers operating on the movement area’

Supported by, e.g.

Ramp Resource Management (RRM) – Ground Training Syllabus:
HEWABI – European NAA activities/fleet leaders:

Further to CAA-UK Composite Workshop (26/4/13 London Gatwick), intended to address arrival of the new large composite pax aircraft fleets: (CAA, BA, Virgin, Thompson, EASA, Boeing, Cranfield University, Service Air)

Actions:

- CAA will re-engage with operators within 1-2 years to review ground handling reports across all fleets;
- CAA will engage with EASA to discuss:
  - share data regarding HEWABI events
  - reviewing any data on ad-hoc strip downs of a/c that might reveal undetected internal damage.
- CAA will investigate the current in-house training regimes/needs for the surveyor community with regard to understanding the differences in composite damage versus metallic structural damage.

Next meeting to be organised by CAA-UK
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HEWABI – need to improve databases:

- current databases limited – ground events not well captured


<table>
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<th>Sum of Number</th>
<th>Column Labels</th>
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<th>Incident</th>
<th>Serious Incident</th>
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1.7E-08 impacts/cycle
Composite Safety Issues

ECCAIRS European Central Repository 2007-2014: CS25 EASA MS Occurrences reported by operators to the NAAs through their Mandatory reporting systems.

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<th>Column Labels</th>
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<th>Incident</th>
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Database improvements:
- extend database access (improvements planned in November 2015)
- improve taxonomy

9.65E-07 impacts/cycle
Questions?
EASA Developing R&D:

1/ Sandwich Disbond – Airbus/NASA/CMH-17 (R. Hilgers etc)
Composite Safety Issues

EASA R&D: EHSDC

Partners Involved

- James Ratcliffe/ NASA
- Ralf Hilgers/ Airbus
- Sönke Fimmen/ Airbus
- Dan Adams/ Utah
- Ralf Schäuble / FhG*
- Waruna Seneviratne/ NIAR
- Christian Berggreen/ DTU*
- Yannick Albertone/ DuPont
- Ley Richardson/ DuPont USA – D30.09 co-chair
- Ronald Krueger/ NIA – CMH-17 Disbond/Delam co-chair
- Leif Carlsson/ FAU*
- George Kardomateas/ GATech*
EASA Developing R&D:

2/ Ageing Composites – EASA – EU
Questions Regarding Accelerated Ageing: Example

Interfacial ageing of high temperature carbon/bismaleimide composites **Adrian Lowe, Bronwyn Fox, Vincent Otieno-Alego**

Ageing studies were performed on a carbon fibre–bismaleimide (CBR320/328) system developed by the CSIRO in Australia, with a fibre volume fraction of 55%. This material has a glass transition temperature of 302 °C and the effect of ageing at 204 and 250 °C on the interfacial region was studied. A variety of test techniques were employed to characterise interfacial property changes (mode I delamination, SEM, Raman); chemical changes due to ageing (Raman, FTIR); changes in glass transition temperature (DMTA) and weight loss. The results showed that both interfacial and resin degradation mechanisms differed between the two temperatures. It can, therefore, be concluded that accelerated ageing is not applicable to this system.

- potentially different ageing responses
- how do you select appropriate accelerated ageing?
- does it matter for lower cure airframe systems?
Physical Aging of Epoxy Polymers and Their Composites
G.M. Odegard and A. Bandyopadhyay


- it is clear that physical aging involves the simultaneous reduction of free volume and conformational changes of the crosslinked molecular structure when exposed to sub-$T_g$ temperatures for extended periods of time. The changes in the molecular structure result in bulk-level responses of epoxies. Specifically; mechanical, thermodynamic, and physical properties of epoxies are influenced in a manner that significantly alters the overall response of these materials.

- matrix properties important for shear and compression
- degradation beyond the direct $T_g$ issue
Several studies have been conducted on the physical aging of fiberous epoxy composites. In general, these studies indicate that the composite material response to physical aging is very similar to the corresponding response of neat epoxy resin. The presence of glass or carbon fibers has little influence on the physical aging characteristics. It is also clear that physical aging has little influence on the strength of the fiber/epoxy interface, which indicates that physical aging does not alter the load-transfer characteristics of fiber-reinforced composites.