CMH-17 Fatigue & Damage Tolerance

Proposed Aging Content for Rev. H Updates

Prepared for

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Composite Aging – CMH-17 D&DT Priority for Rev. H

Current Practice for Composite Aging

- Current industry practices have generally enabled composite structures to avoid safety related aging mechanisms.
- Documentation of these practices is critical for the successful development of new and novel applications and the development of safe composite structures by applicants with minimal or no experience with major composite components.

CMH-17 Plan for Aging, Damage Accumulation, and LOV

- Document current practices to avoid aging mechanisms for composite structures, including:
  - *Long-term material degradation*
  - *Repetitive impact damage and damage accumulation.*
- Include considerations for Limits of Validity (LOV) and composites environmental deterioration (ARAC input).
- Include considerations for substantiation, full-scale testing, and in-service inspections to monitor accidental and environmental damage assumptions used in design.

Document industry practice and include key points from ARAC Final Report.

ARAC Final Report Key Inputs (1 of 5)

Aging Mechanisms (from Executive Summary)

- *"…that guidance materials need updates to address the several definitions":*
  - ***Aging*** *– AC20-107B should be updated to address aging and the LOV*
  - ***LOV*** *– Applies to composite, metallic and hybrid materials*
  - *WFD– As addressed for metallic materials in AC25.571-1D*
  - ***Repetitive impact damage*** *– AC20-107B should be updated to reflect this aspect of aging*
- *"The FAA should revise policy statements to state that* ***the LOV concept applies to both composite and metallic materials,*** *although the aging mechanisms are different for each type of structure."*

Section 3.4.2: Proposed Aging definition:

- *"Response of an aircraft structures material system in service to* ***long-term exposure environments****. A fundamental understanding of the* ***physical or chemical phenomena causing changes in the molecular structure of resins and epoxy-based materials*** *to occur (e.g. exposure to extended periods of sub-Tg temperatures).*
- *This can result in* ***mechanical, thermodynamic, and physical properties affected in ways that can compromise the reliability of resin-based engineering components and structures."***

ARAC Final Report Key Inputs (2 of 5)

Section 3.4.1: Rule changes:

- **<u>Modifications to § 25.571</u>** to be less metallic centric:

  "Change the word "corrosion" to "<u>environmental deterioration</u>" *to cover composite structure equally well and use "environmental conditions" for loading spectra paragraph."*

Section 3.4.2: Guidance changes:

- **<u>AC 20-107B update</u>** to **§ <u>6-d</u>** 'environmental considerations'

  "The <u>effect of aging</u> *on static strength, fatigue, stiffness properties and design values should also be* ***characterized for the material system through <u>testing or analysis supported by test or in-service evidence</u>.*** *Aging may include effects such as UV radiation, erosion and viscoelastic behavior…"*

  "Some further characterization may be required at the design level to ***address aging mechanisms accounting for any specific structural detail design <u>not established as reliable given previous design experience</u>.****"*

ARAC Final Report Key Inputs (3 of 5)

Section 3.4.2: Guidance changes (cont.):

- **AC 20-107B update** to **§ 7-f** Proof of Structure – Static

  *"When a threat assessment demonstrates the likelihood of **repetitive impact damage**, **the accumulated impacts for those structural areas should be addressed and satisfy Category 1 guidance as stated in paragraph 8.a.** …"*

  "This includes consideration of impactor type and geometry, which are to be representative of the defined threat and consider energy levels that satisfy the Category 1 visual (or other selected field inspection procedures) guidance. For example, repetitive impacts can occur in the same location where ground handling operations contact the airplane on a repeatable flight cycle basis and there is a documented known history of impact damage."

- **AC 20-107B Appendix 2** - Definitions

  *"**Repetitive Impact Damage:** **Multiple concentrated impact damage in the areas of the structure supported by a documented threat assessment.** When using a visual inspection procedure, the impact damage is at the threshold of reliable detection and treated as BVID category 1 damage. For example, this can occur due to in-service ground handling operations occurring where operations are repeatable on a flight cycle basis."*

ARAC Final Report Key Inputs (4 of 5)

Section 3.4.2: Guidance changes (cont.):

- **AC 20-107B update** to **§ 8-b** Proof of Structure-Fatigue and Damage Tolerance

  *"**Service data collected over time can better define impact surveys and design criteria** for subsequent products, as well as establish more rational inspection intervals, maintenance practice and **identify locations that may be affected by repetitive impact damage** occurrence. In review of such information, it should be realized that the most severe and critical impact damage, which are still possible, may not be part of the service database if it was derived from visible surface damage detection criteria."*

ARAC Final Report Key Inputs (5 of 5)

Section 3.4.2: Guidance changes (cont.):

- **Include “LOV” in AC 20-107B** where **§ 8c** mentions ‘Extension in service life’.

  “…Composite structure is typically fatigue resistant to operational loads even when considering allowable damage states that are detectable through visual means. However, ***composite structure remains part of the LoV assessment based on the initial engineering data. For certain airframe designs, composites may become the controlling element****. Any proposed extension in LoV needs evaluation per 14 CFR §25.571 and AC25.571-1E or 14 CFR §26.23.* ***Additional maintenance actions may be necessary if the initial structural maintenance program does not preclude in service widespread environmental deterioration.”***

- **Add LOV definition** to **AC25.571-1D, AC20-107B and AC120-104**

  “For metallic structures, *the demonstration must show that* ***WFD will not occur before the LOV.”***

  “For composite structures, *the demonstration must show that* ***any known aging mechanism that degrades the structure below residual strength will not occur before the LOV.”***

CMH-17 Updates – Section 12.6.1 & 12.6.2

12.6 Durability and Damage Growth Under Cyclic Loading

- 12.6.1 Influencing factors
  - 12.6.1.1 Definitions for cyclic loading and S-N curves
  - 12.6.1.2 Cyclic stress ratio (R-ratio) and spectrum effects
  - **12.6.1.3 Environment and thermal cycling**
  - **12.6.1.4 Visco-elastic effects**
  - 12.6.1.5 Damage mechanisms
  - 12.6.1.6 High-cycle fatigue
- 12.6.2 Design issues and guidelines
  - 12.6.2.1 Design details
  - 12.6.2.2 Damage tolerance considerations
  - **12.6.2.3 Aging considerations**
- 12.6.3 Test issues
  - <subsections not shown>
- 12.6.4 Analysis methods
  - <subsections not shown>

Rev H Updates (In-Work)

- Significant new content including sections on environmental cycling and visco-elastic effects (related to aging)

Rev H Updates (In-Work)

- New section summarizing aging issues with input from ARAC.

12.6.1.3 Environment and thermal cycling

Status

- Text is in the final stages of Yellow Pages to incorporate comments from reviewers.
- Authors: Scott Finn and DM Hoyt

Section 12.6.1.3

- Has received several rounds of CMH-17 WG review and is in Yellow Pages review.

Content Summary

- "*This section addresses the effects of **environment and thermal cycling on durability and damage growth** behavior under mechanical cyclic loading. Thermally-induced cyclic loads in hybrid composite/metal construction are addressed in Section 12.3.3.6.*"
- Effect of environmental exposure (e.g., hot temperature hold), environmental conditioning (e.g., moisture saturation), and mechanical testing at environment (e.g., fatigue testing at hot or cold temperatures).
- Contribution of thermal cycling to fatigue damage, especially in interlaminar or matrix-dominated damage modes.
- Effect of moisture absorption during service; i.e., can cause a shift in the stress ratio, R, even if the overall stress range is unaffected.

12.6.1.4 Visco-elastic effects

Status

- Text is in the final stages of Yellow Pages to incorporate comments from reviewers.
- Authors: Scott Finn and DM Hoyt

Section 12.6.1.4

- Includes overview to clarify that visco-elastic effects are only a concern in specific cases.
- Ready for Yellow Pages.

Content Summary

- *"The aerospace **industry normally avoids designs where visco-elastic effects need to be considered**. This is typically done by ensuring that significant structural loads are carried by the fibers, and by appropriate selection of materials for the application and design environments. However, **in certain cases, the visco-elastic behavior of polymer matrices should be considered**. Such cases may include designs with significant structural load transfer through **bonded or co-cured splice joints or applications with sustained high temperatures** or other specific environmental conditions (e.g., components in or near propulsion systems)."*
- Effect of time dependent ply-level stresses, including effect of material and service environment.
- Effect of residual stress relaxation and potential effect on static strength and fatigue life over time for some designs (e.g., highly-loaded bonded or co-cured spice joints).
- Effect of stress "ratcheting" and related effects of moisture absorption.

12.6.2.3 Aging considerations

Status

- Proposed content has been presented and initial feedback received.
- Next step is to draft new text based on the content and industry best practices outlined in the following slides.
  - *Aiming to have first draft by next CMH-17 meeting.*
  - *Draft will be posted to forum then comments and feedback will be discussed at CMH-17 D&DT Task Group meetings until content is ready for Yellow Pages.*

Section 12.6.2.3

- Ready to start draft text based on proposed content.

Feedback on Proposed Content To-Date

- Feedback received during Industry/Regulatory Composite WG (Belfast, June 2018).
  - *Proposed content is aligned with ARAC Final Report & I/R WG input.*
- Feedback received during CMH-17 Task Group meeting (Charleston, July 2018)
  - *Input has been incorporated.*

Aging – Summary of Proposed Content

Definition & Background

- What is aging?
- Background and history, and lessons learned

Industry Best Practices

- Why has aging not been a significant issue to-date in aircraft design?
- What must be considered when evaluating a design for aging?
- How are designs substantiated for aging?

Links to Related Content and Guidance

- Other related content in other CMH-17 sections
- References to related FAA/EASA guidance including ARAC report
- References to aging R&D and literature

Aging – Definition & Background

Definition: What is aging?

- Degradation of properties over time, including visco-elastic effects.
- Moisture ingress, erosion due to bad design details.
- Multiple interacting impacts and/or repairs.
- Relationship with wearout, damage accumulation, limits of validity (LOV)
- Definition from ARAC report.

Background, History, and Lessons Learned

- ARAC final report input - Section 3.4
  - *Current design and maintenance practices have evolved to control aging (e.g., sandwich structures).*
  - *Also points out need for updated guidance to make “regulatory expectations more evident”.*
- Ilcewicz & Ashforth white paper and/or book chapter
- Kevlar in 1980s, lessons learned

Aging – Industry Best Practices (1 of 4)

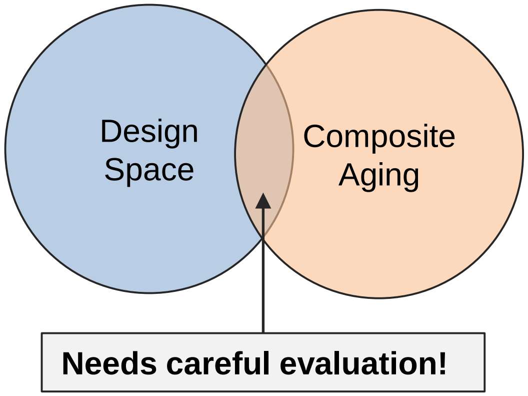
Design Practice

- Understand aging mechanisms and generally avoid them by design.
- Use material screening to avoid materials (types and forms) that are susceptible to aging.
- Generally use traditional designs and materials (with service history).
- Carefully evaluate aging for new and novel designs and material forms.

Fatigue Loading

- Understand cycle strain levels and generally keep operating strain levels low enough to maintain “no growth” of impacts and defects.
  - *Stay below strains that would make composites fatigue sensitive.*
  - *Keep strains low enough that multiple impacts are not likely to coalesce (and reduce strength).*

Current design practice and material choices generally avoid aging through careful evaluation of details that are known to be susceptible.



Aging – Industry Best Practices (2 of 4)

Design Details

- Pay careful attention to primary load paths through bonded joints/matrix.
  - *Understand strength and fatigue sensitivity to visco-elastic effects, stress relaxation, and bondline aging.*
- Carefully evaluate fatigue-sensitive design details.
  - *In particular, understand fatigue behavior for details with out-of-plane loading in the presence of impacts or interlaminar/bondline defects.*
  - *See examples in section 12.6.2.1 Design details.*
- Carefully design sandwich structures and associated design details.
  - *Evaluate design details for potential water ingress.*
  - *Consider facesheet disbond growth and arrestment.*
  - *Establish design guidelines for minimum core densities, minimum facesheet thicknesses, etc.*

In-Service & Repair Considerations

- Consider reparability of structural details that are prone to in-service damage accumulation and/or are susceptible to erosion.
- Consider multiple repairs over lifetime interacting.

Aging – Industry Best Practices (3 of 4)

Knockdown Factors

- Consider the use of strength knockdown factors in cases where material degradation due to environmental exposure cannot be avoided. For example:
  - *Residual strength reduction due to fatigue cycling at environment.*
  - *Degradation of bondlines due to long-term environmental exposure.*
- Similar environment compensation factors may also be used during testing.
  - *Reference section 12.6.3.7 Test Environment*
- Note that these factors are typically only used in cases where it is appropriate based the service environment of the application (e.g., engine components or aircraft with a specific hot/wet service environment).

Repetitive Impact Damage & Damage Accumulation

- Evaluate the effect of damage accumulation and possible interactions between damage threats that could lead to widespread degradation.
- Identify high risk impact areas and demonstrate no growth in test program with multiple BVID impacts. Address multiple impacts in inspection tasks. (Ref. Boeing)
- Damage in general structure is NOT widespread and is randomly distributed. High risk areas covered by test program and design philosophy. (Ref. Boeing)

Aging – Industry Best Practices (4 of 4)

Substantiation

- Perform large-scale “no-growth” fatigue testing with a wide range of impacts, including a residual strength test to show no degradation.
  - *Category 1 → Category 2/3, representative energy levels (deterministic or probabilistic, depending on OEM).*
  - *Multiple impacts (potentially interacting) for areas of structure with high exposure to impact (e.g., cargo door surrounds).*
- Limits of Validity (LOV) are generally controlled by metal structure but environmental degradation of composites must be considered.

Service History and Lessons Learned

- Accelerated testing can’t cover all aspects of in-service environment, aging, or multi-site accidental damage over life of the aircraft.
  - *Need to monitor accidental and environmental damage over time.*
  - *Consider flight hours vs. flight cycles vs. calendar time.*
- Perform early inspection of critical locations (especially for new materials/construction) that would provide indication of erroneous assumptions (“fleet leader” programs).
  - *Fleet leader may be by NDI (not necessarily tear down) or by “keeping an eye on” cracking paint, tell-tale signs followed by “biopsies”.*

Aging – Links to Related Content and Guidance (1 of 2)

The proposed subsection will be in the context of "design issues" and will point to other sections and sources for related guidance.

12.3 Design Development and Substantiation

- 12.3.1 Damage threat assessment
  - *Repetitive impact damage*
- 12.3.2.6 Relationship among categories of damage
  - *Combination of damage criteria keeps strains low (avoids fatigue/aging)*

12.4 Inspection for Defects and Damage

- 12.4.4 EDR & ADR and 12.4.5 Fleet leader programs
  - *In-service inspection aspects. Tie back to assumptions and inspection methods, fleet leader programs, purpose, strategies, sampling vs. specific aircraft.*

12.5 Damage Resistance

- 12.5 Damage resistance, finishes, corrosion, erosion, etc.

12.6 Durability and Damage Growth Under Cyclic Loading

- 12.6.1.3/4 Environment and thermal cycling / Visco-elastic effects
- 12.6.2.1 Design details
- 12.6.3.7 Test environment

Aging – Links to Related Content and Guidance

CMH-17 Chapters on M&P and Testing

- TBD sections covering material screening, environmental protection, coatings and finishes, etc.

Regulatory Guidance

- AC 20-107B § 6 (d) Environmental Considerations, § 6 (e) Protection of Structure, as well as relevant part of § 7 and § 8.
- 25.571 ARAC Final Report and related guidance updates
- EASA NPA-2013-07, Part 26 26-300.

Literature & Other Related References

- TBD