CMH-17 Fatigue & Damage Tolerance

Initiatives and Priorities for Rev. H Updates

Prepared for

Joint CMH-17-EASA-FAA Workshop on Damage Tolerance

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Introduction

Background

- Many updates have been made to CMH-17 over the past 10+ years focused on key safety-related areas identified by the regulators (FAA/EASA/TCCA) and industry leaders.
- One main goal has been to benchmark accepted industry practice relative to regulations and associated guidance.
  - *Currently incorporating information from Aviation Rulemaking Advisory Committee (ARAC) on Damage Tolerance and Fatigue.*

The CMH-17 Rev. H status, priorities and proposed content have been updated based on latest progress.

Objectives

- Provide a roadmap of CMH-17 Fatigue and Damage Tolerance (F&DT) initiatives.
- Outline content completed, in-work or planned for next revision **(Rev. H).**

CMH-17 F&DT Priorities for Rev. H (1 of 2)

Hybrid Issues for Composite-Metal Assemblies

- Thermal Loads
  - *Analysis and test requirements*
  - *Industry current best practices*
  - *Example case studies*

ARAC Report Section 3.3:
Testing of Hybrid Structure

Repeated Load Tolerance & LEF Guidance

- LEF Guidance
  - *Emerging approaches for LEFs for hybrid FSFT*
  - *Multi-LEF (already in Rev. G), Deferred Severity Spectrum*
  - *High-LEF details at subcomponent level*

CMH-17 Section 12.6.3:
D&DT Test Issues

Damage Threat Assessment

- Part 25 large vs. Part 25 small / Part 23
  - *Damage threat vs. criteria for specific structure or AC type*

ARAC Report Section 3.1:
Threat Assessment

CMH-17 F&DT Priorities for Rev. H (2 of 2)

Categories of Damage & HEWABI

- Relationship among categories & minimum damage sizes
  - *Shape of the residual strength curve*
  - *Minimum damage sizes for large (structural) damage capability*
- HEWABI & CAT 5 Damage
  - *Updates based on Policy Statement and latest R&D*

ARAC Report Section 3.2:
Structural Damage Capability

ARAC Report Section 3.8:
Structural Inspections and ALS

Composite Aging, LOV, and Damage Accumulation

- Current practices resulting in avoidance of safety related aging mechanisms for composite structures
- Composite considerations for LOV

ARAC Report Section 3.4:
Aging Mechanisms

ARAC Report Section 3.9:
Harmonize EASA Aging Aircraft Rulemaking

Building Blocks for Analysis Supported by Test

- Relationship between analysis and test
- Appropriate scale for substantiation

CMH-17 Section 4.3.7:
BB Analysis Validation

CMH-17 F&DT Other Topics for Rev. H

Additional Topics

- Flights with Known Damage and Defects
- Maintenance Inspection Technology
- Application of Probabilistic Methods
- Smarter Testing

ARAC Report Section 3.5:
Inspection Thresholds

ARAC Report Section 3.8:
Structural Inspections and ALS

Topics Covered Elsewhere

- Bonded joints and bonded repairs
- Sandwich disbond

CMH-17 updates are in-work by others (Borgman, Krueger, et. al.)

Priorities from Industry/Regulatory Working Group

Priorities from Industry/Regulatory Working Group

- "*Key components of composite fatigue and damage tolerance and related maintenance practice that are typically addressed during type certification*"

- Agreed on several "**key aspects**" to focus on for each priority topic relative to safety and certification.
- The key aspects were rated by importance:
  - ***Most Important***
  - ***Needed***
  - *Desired in Time*

- The priorities established by the Industry/Regulatory Working Group generally align with the technical areas studied by the **Part 25 § 25.571 ARAC**.

Key aspects defined by the Industry/Regulatory Working Group align with the areas covered by the §25.571 ARAC.

Color-coded "key aspects" for each priority topic.

§ 25.571 ARAC Final Report

REFERENCE

§ 25.571 ARAC Final Report

- Aviation Rulemaking Advisory Committee
- Transport Airplane Metallic and Composite Structures Working Group (TAMCSWG) – Recommendation Report to FAA
- Document provides a strong conceptual basis for many priority topics.
  - *Evaluate current § 25.571, subparts C and E of part 26, and guidance material*
  - *Recommend Rule or Guidance changes*
  - *Estimate the Costs and Benefits associated with any changes*

The ARAC Final Report was reviewed with the goal of aligning the new content for CMH-17 Rev. H.

§25.571 ARAC Final Report

Transport Airplane Metallic and Composite Structures Working Group – Recommendation Report to FAA

RELEASE/REVISION	RELEASE DATE
Final	**June 27, 2018**

CONTENT OWNER:

Transport Airplane Metallic and Composite Structures Working Group

All revisions to this document must be approved by the content owner before release.

REFERENCE

§ 25.571 ARAC Draft White Paper (Ilcewicz/Sippel)

- "***Goal:*** *Document key points on potential §25.571 rule change and the related future guidance needs based on ARAC discussions and a review of progress in documenting industry recommendations.*"

- Document is in **DRAFT** form but provides a strong conceptual basis for many priority topics.
  - *Living document, expected to change throughout ARAC process in order to build consensus before including in industry guidelines, guidance, or rules.*

Key content from the §25.571 ARAC Draft White Paper was identified as possible input to CMH-17 Rev. H.

§25.571 ARAC Draft White Paper

Transport Fatigue & Damage Tolerance Considerations in Evolving §25.571 (and supporting guidance) **to Address Safety for Both Metals and Composites**

Goal: Document key points on potential *§25.571* rule change and the related future guidance needs based on ARAC discussions and a review of progress in documenting industry recommendations.

§25.571 ARAC task-based approach currently being used (W. Sippel)

a) Schedules and milestones (updated for an extension, with additional details since tasking started)
b) Synopsis of the deliverables (see June 2015 presentations with some updates for current details)

Task 2 Items under consideration

a) Briefly describe how they were derived and justify their need (W. Sippel)
b) Outline any task interactions evident from ARAC discussions (L. Ilcewicz, W. Sippel)
   i) MSG-3 (normal maintenance), ALS, and inspections or other procedures intended to avoid catastrophic failure (e.g., HEWABI has safety management approach involving training, reporting awareness, conditional inspections and robust design practices that avoid questions on whether significant damage has occurred)
   ii) SDC and failsafe have similar purpose and meaning unless the structure has a "single load path characteristic", in which case, other procedures are sought to avoid catastrophic failure (e.g., lower stresses, more regular inspections). Even if SDC and failsafe design practice is possible the failure mode must be evident to ensure the proper inspection is performed (e.g., damage will not always be obvious as is the case for lack of bonded stringer attachment)
c) ID missing tasks or a need to generalize tasks in covering both metals & composites (L. Ilcewicz)
d) Summarize key points derived to date (L. Ilcewicz)
   i) Critical damage threats differ significantly between metals and composites
   ii) Maintenance inspections to avoid catastrophic failure differ for specific damage threats, including those that can't be addressed through DTE (e.g., HEWABI)
   iii) Aging phenomena for metals and composites have unique relationships with damage threats
   iv) Hybrid (assemblies with metal and composite elements) structural considerations appear manageable through current industry practices, supported by minor rule changes
   v) Damage tolerance evaluation (DTE) depend on damage assumptions & inspection limitations
   vi) Baseline maintenance practices, applied with other scheduled inspections derived from DTE are consistent with the composite categories of damage (as defined in AC 20-107B), which are applied to composites to ensure damage threats are addressed in a timely manner
   vii) Structural damage capability (SDC) to reduce potential catastrophic failure is essential to practical DTE and maintenance practices
   viii) Most emerging technologies under consideration for airframe applications should be covered by rules generalized to address metals and composites
   ix) Stringent QC practices and design limitations are used in combination with existing DTE practices to avoid catastrophic failure due to bonding manufacturing defects
e) Document inconsistencies or missing content in recommendations drafted by industry near the end of Task 2 from NAA perspectives (L. Ilcewicz, W. Sippel)
   i) A desire for SDC, which unless it becomes required, may prove to be nothing more than "good design practice". Perhaps we need to consider a less controversial definition. Let's propose SDC as: "The capability of a structure to avoid catastrophic failure considering all the relevant limitations and assumptions associated with damage tolerance analysis/test evaluations and required inspections." Such a definition would have a natural link with the Categories of Damage.

2014 ASC Paper

REFERENCE

2014 ASC Paper [1]

Industry and Regulatory Interface in Developing Composite Airframe Certification Guidance

C. ASHFORTH, L. ILCEWICZ and R. JONES

ASC paper provides regulatory perspective and is a good source for CMH-17 content updates.

ABSTRACT

The Federal Aviation Administration (FAA) has proactively worked with the European Aviation Safety Agency (EASA), Transport Canada (TCCA), and the international industry (domestic and foreign) to develop rules, policy and guidance applicable to the use of composites for many years. This has led to an excellent safety record in applying composite materials and structural bonding to critical airframe components since the 1970s. The emphasis of this paper will cover accomplishments since 1999. The paper will also discuss the background that helps make composite technology a viable option to mature metal technologies.

Since 1999, significant progress has been achieved towards regulatory standards relating to advanced composite material and process control, shared databases, bonding, repair, structural substantiation, fatigue & damage tolerance, inspection, and numerous other areas. The corresponding foundation for safety awareness education supporting structural engineering, manufacturing, and maintenance has also been achieved. The historical perspectives of these developments will be discussed. Finally, a seven year strategic plan will be presented that details future interface with industry for composite regulatory developments.

The FAA initiatives focus first and foremost on the safety of the existing fleet, and secondly on the efficiency of certifying new products. Service experience, such as the Airbus "lost rudder" incident on Air Transat Flight 961 on March 6, 2005, and the Cessna "spar disbond" incident identified in AD 2010-26-54, force priorities in FAA resources. Both historically and moving into the future, a majority of FAA initiatives center on the subjects of fatigue and damage tolerance (F&DT) and structural bonding, with related maintenance activities. Workforce education is a FAA priority that compliments all other initiatives by ensuring the FAA has the knowledge and skill to oversee composite design, manufacturing, and maintenance activities.

Cindy Ashforth and Larry Ilcewicz, Federal Aviation Administration, 1601 Lind Avenue SW, Renton, WA 98057
Rusty Jones, Federal Aviation Administration, 800 Independence Avenue SW, Washington, DC 20591

[1] Ashforth, C., L. Ilcewicz, and R. Jones. "Industry and Regulatory Interface in Developing Composite Airframe Certification Guidance." In *Proceedings of the American Society for Composites (ASC) Twenty-Ninth Technical Conference*. La Jolla, CA, 2014.

REFERENCE

Scaling IPD Composite Airframe – Book Chapter (Ilcewicz/Ashforth)

- ***Goal:*** *"…highlight some past development projects that led to civil airplane applications and the corresponding service experiences", and "discuss barriers to expanding applications before addressing key considerations for composite integrated product development and implementation."*
- Documents a number of practices that allow for composite structures to avoid safety related aging mechanisms.

Documents a number of practices contributing to avoid safety related aging mechanisms, identified as possible input to CMH-17 Rev. H.

Scaling IPD Composite Airframe – Book Chapter

3.2 Scaling Crucial to Integrated Product Development of Composite Airframe Structures

Larry Ilcewicz and Cindy Ashforth, Federal Aviation Administration, Renton, WA, United States

3.2.1 Introduction

The use of advanced composite materials in commercial aircraft structures has increased over time. Small airplanes and rotorcraft led early applications to critical structures, while transport aircraft use of composites gradually increased from the 1970s until the turn of the century, when advanced applications to wing and fuselage structure started. The nature of composite materials and fabrication processes used to make composite structures has promoted a multidisciplinary approach to product development, where key integrating functions such as design engineers needed advanced skills in both structures and manufacturing. The integrated product development approach has become essential to current applications, which seek further advances.

The main benefits of composites over metals technology for aircraft products have been structural weight savings, fatigue resistance, and corrosion suppression. Additional strategic defense benefits such as shielding and damage tolerance also led more

26 Comprehensive Composite Materials II, Volume 3 doi:10.1016/B978-0-12-803581-8.10314-5

CMH-17 Volumes for Polymer Matrix Composites (PMC)

Volume 1 – Guidelines for Characterization of Structural Materials

Volume 2 – Materials Properties

Volume 3 - Materials Usage, Design, and Analysis

Volume 6 - Structural Sandwich Composites

CMH-17 Volume 3

1. General Information
2. Introduction to Composite Structure Development
3. **Aircraft Structure Certification and Compliance**
4. **Building Block Approach For Composite Structures**
5. Materials and Processes
6. Quality Control of Production Materials and Processes
7. Design of Composites
8. Analysis of Laminates
9. Structural Stability Analyses
10. Design and Analysis of Bonded Joints
11. Design and Analysis of Bolted Joints
12. **Damage Resistance, Durability, and Damage Tolerance**
13. **Defects, Damage, and Inspection**
14. **Supportability, Maintenance, and Repair**
15. Thick-section Composites
16. Crashworthiness and Energy Management
17. Structural Safety Management
18. Environmental Management

Supporting discussions

Main D&DT content

Supporting discussions

Ch. 12: Damage Resistance, Durability, and Damage Tolerance

12.1 Introduction

12.2 Rules, Requirements and Compliance for Aircraft

12.3 Design Development and Substantiation

12.4 Inspection for Defects and Damage

12.5 Damage Resistance

12.6 Durability and Damage Growth Under Cyclic Loading

12.7 Residual Strength

12.8 Application/Examples

12.9 Supporting Discussions

Content on most priority topics is contained in these sections.

CMH-17 Updates – Section 12.2

12.2 Rules, Requirements and Compliance for Aircraft

12.2.1 Civil aviation regulations and guidance

12.2.1.1 Static strength with damage

12.2.1.2 Damage tolerance and fatigue

12.2.2 Categories of damage

12.2.2.1 Category 1

12.2.2.2 Category 2

12.2.2.3 Category 3

12.2.2.4 Category 4

12.2.2.4 Category 5

12.2.2.6 Factors affecting placement of damage in categories

12.2.3 Load and damage relationships

12.2.4 Compliance approaches

12.2.4.1 Deterministic compliance method

12.2.4.2 Probabilistic or semi-probabilistic compliance methods

Rev H Updates (Proposed)

- AC 25.307-1?

Rev H Updates (In-Work)

- HEWABI Policy Statement
- Relationship among categories

CMH-17 Updates – Section 12.3

12.3 Design Development and Substantiation

12.3.1 Damage Threat Assessment

12.3.2 Damage design criteria

12.3.2.1 Category 1

12.3.2.2 Category 2

12.3.2.3 Category 3

12.3.2.4 Category 4

12.3.2.5 Large damage from undefined events

12.3.2.6 Relationship among categories of damage

12.3.3 Substantiation

12.3.4 Addressing Category 5 damage

12.3.5 Additional design development guidance

Rev H Updates (In-Work)

Rev H Updates (In-Work)

- SDC and minimum damage sizes
- Relationship among categories (including new section)

Rev H Updates (Complete)

Rev H Updates (In-Work)

- HEWABI Policy Statement

Rev H Updates (In-Work)

- Relationship among categories

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.

CMH-17 Updates – Section 12.6.3

12.6 Durability and Damage Growth Under Cyclic Loading

- 12.6.1 Influencing factors
- 12.6.2 Design issues and guidelines
- 12.6.3 **Test issues**
  - 12.6.3.1 Scatter analysis of composites
    - 12.6.3.1.1 Individual Weibull method
    - 12.6.3.1.2 Joint Weibull method
    - 12.6.3.1.3 Sendeckyj equivalent static strength model
  - 12.6.3.2 Life Factor approach
  - 12.6.3.3 **Load Factor approach**
  - 12.6.3.4 **Load Enhancement Factor approach**
    - 12.6.3.4.1 **LEFs for complex structure**
    - 12.6.3.4.2 **Testing Requirements**
    - 12.6.3.4.3 **Considerations for Metal/Composite Hybrid Structure**
  - 12.6.3.5 Ultimate Strength approach
  - 12.6.3.6 **Test spectrum development**
  - 12.6.3.7 Test environment
  - 12.6.3.8 **Damage growth**
- 12.6.4 Analysis methods

Rev H Updates (Complete)

- LEF guidance
- Emerging approaches and load sequencing

Rev H Updates (In-Work)

- Test spectrum development

Ch. 4: Building Block Approach for Composite Structures

Content on building block priority topic is included in this section.

4.1 Introduction and Philosophy

4.2 Rationale and Assumptions

4.3 Methodology

4.4 Considerations for Specific Applications

4.5 Special Considerations and Variances for Specific Processes and Material Forms

CMH-17 Updates – Section 4.3

4.3 Methodology

- 4.3.1 Failure modes
- 4.3.2 Analysis
- 4.3.3 Material qualification and allowables (coupon level)
- 4.3.4 Design detail allowables (element test level)
- 4.3.5 Critical structure pre-production assurance (subcomponent test level)
- 4.3.6 Full-scale structure validation—component level tests
- **4.3.7 Analysis validation**

Rev H Updates (In-Work)

- Protocol for Analysis and Test Correlation/Structural Substantiation