FAA / CAAs “Composite Meeting”
- AC 20-107B Content Review -

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Composite Safety & Certification Meeting
- AC 20-107B Content Review -

- Para. 1-5 (opening paragraphs)
- Para. 6: Material & Fab. Development
- Para. 7: Proof of Structure – Static
- Para. 8: Proof of Structure – F&DT
- Para. 9: Proof of Structure – Flutter+
- Para. 10: Continued Airworthiness
- Para. 11: Additional Considerations
  - Crashworthiness
  - Fire Protection, Flammability & Thermal Issues
  - Lightning Protection
- Appendices
AC 20-107B Outline

1. Purpose
2. To Whom This AC Applies
3. Cancellation
4. Related Regulations & Guidance
5. General
6. Material and Fabrication Development
7. Proof of Structure – Static
8. Proof of Structure – Fatigue & Damage Tolerance
9. Proof of Structure – Flutter & Other Aeroelastic Instabilities
10. Continued Airworthiness
11. Additional Considerations

Appendix 1. Applicable Regulations & Relevant Guidance
Appendix 2. Definitions
Appendix 3. Change of Composite Material and/or Process
(EASA CS 25.603, AMC No. 1, Para. 9 and No. 2: Change of Material)
Color-Coded Scheme for Review of AC 20-107B Content

Green text indicates it came from AC 20-107A, with little or no change

Blue text suggests that it is considered a minor addition that provides general guidance

Red text highlights that it is considered a major addition that provides more detailed guidance (or a significant deletion)
Changes to Introductory Paragraph 1 – 5

Paragraph 1: Purpose
- Retains link with Parts 23, 25, 27 and 29 type certification requirements
- Some wording changes (e.g., left only carbon & glass as examples of fiber types)

Paragraph 2: To Whom it May Concern
- applicants, certificate/approval holders, operators, parts manufacturers, material suppliers, maintenance and repair organizations

Paragraph 3: Cancellation (AC 20-107A, April 25, 1984 will be cancelled)

Paragraph 4: Regulations Affected (very minor change)

Paragraph 5: General
- Retained AC 20-107A text for 4a. & 4b. (AC acceptability & intro statements)
- 4a. Added rationale for periodic updates (evolution of composite technology, data from service experiences and expanding applications)
- 4a. Added thoughts that the AC guidance is most appropriate for “critical structures” essential in maintaining overall flight safety of the aircraft
- 4b. Added general statements on: 1) issues unique to specific materials and processes and 2) a need to consider the anisotropic properties and heterogeneous nature of composites as evident in scaled processes
Para. 6: Material & Fabrication Development

Retained AC 20-107A text from 5a., 5b., 5c. & 5d. (but outline changes made due to added content)

New opening paragraph on need for qualified materials & processes
– Justified by effect of material & process control on composite performance

6a. Material and Process Control (new subsection)
– Opens with content from AC 20-107A, Paragraph 9f. (Production Specs)
– Includes content taken from AC 20-107A Paragraph 9e. (Quality Control)
– New content expanding on discrepancies & QC text from AC 20-107A
– Reference to Appendix 3 (containing info on “Change of Material” taken from CS 25.603, AMC No. 1 & 2)
– New content on material requirements based on qualification test results
– Environmental durability tests recommended for structural bonding
– New content on a need to demonstrate repeatable processes at sufficient scale as related to material and process control of product structural details
– Added note that regulatory bodies don’t certify materials & processes independent of aircraft product certification
– Words on need to link material specs & process info with shared databases
– New content on equivalency sampling tests for new users of shared databases

Content increased from 0.5 to 5 pages
Para. 6: Material & Fabrication Development

6b. Manufacturing Implementation (new subsection)
   – New content on use of specifications and documentation to control materials, fabrication and assembly steps in the factory
   – New content on control of the environment and cleanliness of manufacturing facilities to levels validated by qualification and proof of structure testing
   – New content on production tolerances validated in building block tests
   – New content on manufacturing records of allowed defects, rework and repair
   – New content on “new suppliers for previously certified aircraft products”

6c. Structural Bonding (new subsection not using the word secondary)
   – New content outlining the need for qualified materials and bond surface preparation for metal bonding and composite secondary bonding
   – New content on physical, chemical and mechanical qualification tests, including tests for evaluating proper adhesion (e.g., some form of peel test)
   – New content on in-process control of critical bond processing steps
   – An explanation of the intent of 14 CFR 23.573(a)(5) for damage tolerance substantiation of structure with bonded joints (explanation of the 3 options in addition to a well-qualified bonding process and rigorous QC)
   – Thoughts on actions taken for adhesion failures found in service
Para. 6: Material & Fabrication Development

6d. Environmental Considerations (based on AC 20-107A, 5a.)
   - Retains all text from AC 20-107A, 5a.
   - Added sentence on substantiating accelerated test methods
   - Added sentence on need to consider residual stresses for dissimilar materials

6e. Protection of Structure (based on AC 20-107A, 9d. of same name)
   - Retains AC 20-107A text from 9d. with added words for clarification
   - Adds new sentence on a need to isolate some materials to avoid corrosion

6f. Design Values (based on AC 20-107A, 5b.)
   - Retains AC 20-107A text from 5b with added words for clarification
   - Added sentence on a need to derive design values from parts made using mature materials and processes (under control)
   - Added final sentence with equivalent thoughts for non-laminated composites

6g. Structural Details
   (based on AC 20-107A, merging 5c. and 5d.)
   - Retains AC 20-107A text from 5c. and 5d. (at the start and end)
   - Added a sentence with thoughts on testing for the effects of impact damage
Building Block Test & Analysis Approach Relies on a Strong Connection Between M&P Specs, Mfg. Implementation & Databases

- M&P control require ID of key characteristics & processing parameters that ensure similar microstructure & cure characteristics in coupons, elements, details and real structural components
- M&P specs need to be linked to qualification databases
  - Can be achieved with an inverted building block (but the risk mitigation for proof of structure in component tests is not efficiently accomplished and conformity checks can be difficult)
Definition of Structural Bonding

Differences between
Lamination of uncured resins and adhesives
and
Structural Bonding (i.e., Secondary Bonding) when surface preparation is a critical process step

Taken from
FAA Workshop (6/09, Japan)

Bonded Assembly / Interfaces

CO-CURING: Components cured together
- Component 1 un-cured
- Component 2 un-cured

CO-BONDING: Components bonded together during cure of one of the components
- Comp. 1 cured
- Comp. 2 un-cured
- Adhesive
- Comp. 2 cured
- Comp. 1 un-cured
- Adhesive

SECONDARY BONDING: Components bonded together with separate bonding operation
- Component 1 cured
- Component 2 cured
- Adhesive

Bondline Analysis and Bonded Repairs

Federal Aviation Administration

FAA / CAAs Composite Safety & Certification Meeting
CAA of Singapore, Singapore; Sep 01-04, 2015
Technical Scope of the 2004 Bonded Structures Workshops

- Material & Process Qualification and Control
- Regulatory Considerations
  - Proof of structure: static strength
  - Fatigue and damage tolerance
  - Design and construction
  - Materials and workmanship
  - Durability
  - Material strength properties & design values
  - Production quality control
  - Instructions for continued airworthiness
  - Maintenance and repair
- General aviation, rotorcraft and transport aircraft
- Design Development and Structural Substantiation
- Commercial and military applications were reviewed
- Repair Implementation and Experience

Bonding applications where at least one side of the joint is metal or pre-cured composite

Manufacturing Implementation and Experience
Progress for Bonded Structures (CE E)

Action Groups for Detailed Documentation

- Some guidance for bonded structures, which comes from military and commercial aircraft experiences, was documented in a TTCP report
  - Chairman: Jack Lincoln, WPAFB
  - Composite and metal bonding
  - Starting point for FAA bonding initiatives

- FAA policy for bonded joints and structures was released in Sept., 2005

Purpose

1. To review the critical safety/technical issues
2. To highlight some of the successful engineering practices employed in the industry
3. To present regulatory requirements and certification considerations pertinent to bonded structures

- Part 21 AC planned for FY16 to FY20
Why Environmental Durability Tests of Composite Bonded Joints?

• “There is currently no known mechanism similar to metal-bond hydration for composites”
• Ensure long-term environmental durability of composite bonds, including time-related changes in stress
• Investigate effects of environmental exposure on performance of bonded composite joints
  – Failure mode: cohesion versus adhesion failure
  – Estimate fracture toughness reduction
• Assess effectiveness of surface preparation and all “Known Factors” affecting bond strength

As a result, “Composite Environmental Durability” remains a priority for FAA research supporting bond initiatives
Composite Pt. 25 PSE Structural Bonding & Co-Curing (With Adhesive or Matrix in Critical Load Paths)

A desire to minimize use of mechanical fasteners goes beyond bond reliability & long-term composite durability/aging issues as currently understood

- Current bonded, co-bonded or co-cured applications
  - Some attachments (most stiffener to skins, some frames/spars to skin)
  - Rib to skin attachments on some flight controls, sandwich construction
- Likely advances in the next 3 years
  - Dealing with existing challenges (e.g., surface prep reliability)
  - Automation to remove human factors and add more process control
  - Some advances to minimize “chicken fasteners” (fasteners used only for redundancy)
- Desired advances in the next 7 years
  - Process and inspection breakthroughs
  - Other forms of 3-dimensional fiber reinforcement
  - More unitization in most structures, including fuel tanks

Short Brainstorm Session at May 2014 Composite Transport Industry/Regulatory WG Mtgs.
Composite Structural Bonding & Co-Curing (With Adhesive or Matrix in Critical Load Paths)

*Technical challenges for advanced applications*

- **Material and process qualification**
  - Adhesive/substrate/surface prep combinations (material & process control)
  - Critical material and process parameters, combined with control

- **Structural design development and substantiation**
  - Potential peel and shear time-dependent/history (load, environment)-dependent changes in failure modes, residual strength and creep/fatigue (multi-site damage) - life
  - Impact sensitivities local to larger scale (HEWABI conditional inspections)

- **Manufacturing implementation**
  - Tooling complexities to ensure more elements meet the necessary tolerances that facilitate bond and/or co-cure contact
  - Defect characterization/assessment/disposition/repair
  - Multiple cure cycles
  - Maintaining proper documentation on the past history of processing

- **Maintenance implementation**
  - Repair-ability, inspect-ability, disassembly and replacement
  - Educational aspects (from handling through repair and replacement)
  - Future modification

**Short Brainstorm Session at May 2014 Composite Transport Industry/Regulatory WG Mtgs.**
Composite Material & Process Control and Shared Databases

- DOD, NASA & FAA have been working together to allow industry self-regulation for shared databases, which support efficient M&P control and generic design data
  - NASA AGATE initiated the efforts in 1995, with FAA help
  - Related FAA policy and guidance exists in this area (since 2003)
  - ASTM international test standards (many supported by FAA R&D)
  - CMH-17 shared test databases for simple, non-product specific M&P control and design properties (in work for 30+ years)
  - AMS P-17 Specifications for material procurement and processing information (in work for 10+ years)

- NCAMP program has demonstrated an acceptable path forward (to be recognized in 2010 FAA policy memo)
  - Conducting FAA 2010 safety awareness workshop in this area
AIR Policy Memo on National Center for Advanced Material Performance (NCAMP)

• FAA Certification Division (AIR-100) released a policy memo (AIR100-2010-120-003, Sept. 20, 2010) recognizing NCAMP composite databases & specifications as compliant with 14 CFR Parts 23, 25, 27 and 29 in regards to 2x.603(a) & (b), 2x.605 and 2x.613(a) & (b), as well as 33.15 & 35.17 for materials used in engine and propeller applications.

• NCAMP has standard operating procedures outlining the organization, methods and processes used to interface with SAE and CMH-17, with minimal regulatory oversight.
Current Regulatory Guidance & Reference Materials of relevance to NCAMP

• Regulatory Guidance and Policy

• Reference Material
  – NCAMP Standard Operation Procedures (SOP), Doc. # NSP 100 (E), dated December 22, 2009
Para. 7: Proof of Structure - Static

Retained AC 20-107A text from 6a., 6c., 6d., 6e. and 6g.

Merged thoughts from AC 20-107A 6b. into 6a.

Eliminated AC 20-107A 6f.

Opening statement

- Kept text from opening statement of AC 20-107A, 6. (moved to middle)
- Added introductory thoughts on what needs to be considered in static strength substantiation based on content in AC 29-2C, MG8 (critical load cases, failure modes, environment, non-detectable damage, allowed mfg. defects)
- Added sentence on necessary experience for analysis validation

7a. Effects of repeated load & environment
(based on AC 20-107A, 6a. & 6b.)

- Starts with the same words as AC 20-107A, 6a.
- Adds a reference to effects of environment on material properties (6d.) and protection of structure (6e.)
- Merges thoughts from AC 20-107A, 6b. on two approaches to account for repeated load and environment (same as fifth area of AC 29-2C, MG8)
Para. 7: Proof of Structure - Static

7b. Building block approach (based on AC 29-2C, MG8)
- Most text taken directly from AC 29-2C, MG8 (2005 version)
- Two figures added to support the text
- Additional generic descriptions justifying use of a building block approach

Figure A. “Schematic diagram of building block tests for a fixed wing

Figure B. “Schematic diagram of building block tests for a tail rotor blade
Para. 7: Proof of Structure - Static

7c. Component static test (identical to AC 20-107A, 6c.)
   – May be redundant with new content provided in 7a.

7d. Processing of static test article (based on AC 20-107A, 6d.)
   – Initial text is identical to AC 20-107A, 6d.
   – Added statement to include defects consistent with limits set by mfg. acceptance criteria

7e. Material & process variability considerations (based on AC 20-107A, 6e.)
   – Keeps the same text as AC 20-107A, 6e. (but removes metal vs composite differences)
   – Adds text from AC 29-2C, MG8 for purposes of clarification.
   – Method 1 is referred to as: “substantiated by analysis supported by tests”
   – Method 2 is referred to as: “substantiated by tests” (use of overload factors)

7f. Non-detectable impact damage (based on AC 20-107A, 6g.)
   – Starts with the same text as AC 20-107A, 6g.
   – Added “component level” in reference to analysis supported by test evidence
   – Added BVID as an example for visual detection procedures
   – Added sentences on selection of impact sites

7g. One sentence ref. to Appendix 3 for material & process change
Structural Substantiation
Critical Issues for Composite Designs

- Integration of structural design detail with repeatable manufacturing processes
  - Material and process control
  - Traditional building block test & analysis approach is difficult for some new processes

- Design details, manufacturing flaws and service damage, which cause local stress concentration, drive static strength MS
  - Dependency on tests
  - Scaling issues

- Environmental effects
  - Temperature and moisture content

- Repeated load and damage tolerance considerations

- Maintenance inspection and repair
Past Part 23 TC Projects with Extensive Use of Composites in Airframe Structure

Used “an analysis supported by test approach” to avoid overload factors for variability

Raytheon Premier I

PAC USA Lancair LC40-550FG

Cirrus Design Corp. SR20
Today, introducing an additional factor on 1.5 for composites is no longer a debate. The first reason is that the difference in scatter between metals and composites turned out to be lower than previously expected. The second reason is that additional margins provided by accounting for, both the most adverse environmental conditions and the minimum quality of the structure, are reputed to balance any small difference in the scatter between metals and composites.

Moreover, option (a) would not be sufficient to prove an equivalent level of safety, should a difference in variability exist.

Suggestion: to delete the 5.6 sub-paragraph.

J. Rouchon/Propositions for a revision of ACJ 25.603/Feb. 03

5.4 The component static test may be performed in an ambient atmosphere if the effects of the environment are reliably predicted by subcomponent and/or coupon tests and are accounted for in the static test or in the analysis of the results of the static test.

5.5 The static test articles should be fabricated and assembled in accordance with production specifications and processes so that the test articles are representative of production structure.

5.6 When the material and processing variability of the composite structure is greater than the variability of current metallic structures, the difference should be considered in the static strength substantiation by -

a. Deriving proper allowables or design values for use in the analysis, and the analysis of the results of supporting tests, or

b. Accounting for it in the static test when static proof of structure is accomplished by component test.

5.7 Composite structures that have high static margins of safety (e.g., some rotorblades) may be substantiated by analysis supported by subcomponent, element, and/or coupon testing.

5.8 It should be shown that impact damage that can be realistically expected from manufacturing and service, but not more than the established threshold of detectability for the selected inspection procedure, will not reduce the structural strength below ultimate load capability. This can be shown by analysis supported by test evidence, or by tests at the coupon, element, or subcomponent level.
Key Factors to Consider for Proof of Structure - Static

• Applicant’s approach to integrating composite design and manufacturing processes
  – Demonstrated confidence in material and process controls
    ➢ Issues for “major risk-sharing partners/suppliers” for design & manufacturing
  – Test validation of analysis methods for selected structural details, critical load conditions and other factors affecting strength
  – Conformity of design & manufacturing details for integrated structure
  – Large-scale static strength test (final analysis validation versus overload)
    ➢ Minimum analysis and a lack of building block correlation leads to a need to cover “material/process variability” in static overload factors

• Time-related degradation mechanisms that yield undetectable flaws
  – Temperature, moisture and other environmental considerations
  – Repeated load

• *Expected* manufacturing defects and service damages that can’t be detected with selected inspection methods or are allowed
AC 20-107B
Para. 7: Proof of Structure - Static

• Added thoughts on the necessary test experience for analysis validation

• Guidance on use of overload factors
  – Material & process variability
  Method 1: Cert. by analysis supported by test
  Method 2: Cert. by test

• Use of analysis to identify critical load cases and associated failure modes

Figure A. Schematic diagram of building block tests for a fixed wing
Proof of Structure - Static

• **Summary of Key Factors to Consider**
  – Applicant’s approach to integrating composite design and manufacturing processes
  – Account for environmental exposure and repeated load
  – *Expected* manufacturing defects and service damages

• **Considerations for composite structural analysis**
  – Base material properties have limited use
  – Composite failure usually initiates at a stress concentration
  – Semi-empirical analyses supported by building block tests are typically used to address many factors affecting static strength
  – Some issues are best addressed using conservative underlying analysis assumptions (e.g., variability in as-manufactured joints)
  – Anticipate analysis and test iterations between different levels of structural scale
Synopsis of Time-Related Composite Degradation Mechanisms

• Moisture absorption, which occurs over time, combines with high temperature exposure to significantly reduce matrix-dominated strength (e.g., compression)

• Composite materials generally have very good resistance to repeated loading

• Environmental conditions and loads, which result in systematic matrix failure should be understood
  – Best dealt with through material selection and limits on design stress levels, rather than developing a database for the effects on strength, stiffness and function of the part
Time-Related Material Degradation

**Property Changes**
- **Residual strength**
  - Stiffness loss
  - Dimensional stability
  - Physical property changes
  - Matrix damage accumulation

**Nonlinear material behavior**
- Moisture residual stress (swelling)
- Moisture absorption
- Moisture desorption

**Thermal residual stress (shrinkage)**

**Hygro, Thermal & mechanical fatigue**
- Static and dynamic structural loads
- Temperature and moisture dependent pressure gradients in thin-gage laminate honeycomb sandwich panel designs

**Surface Phenomena**
1) Diffusion rate
2) Finish integrity
3) Part location
4) Environmental history

**Ultraviolet exposure**

Covered in more detail by EnvRLoad.ppt SSS Workshop
Known Defects Allowed Into Service (Mfg. Discrepancies that “Pass”)

• Composites are “Notch Sensitive”
  – Can’t take advantage of base strengths
  – Ultimate allowable strengths have knockdowns related to non-detectable damage or common design details (e.g., bolt holes, cutouts)

• Building block test and analysis should recognize the need for “Effects of Defects”
  – Composite airplane programs that ignore this issue have often gone out of business (particularly if they are taking a Structural Substantiation by Test Approach)
  – All possible “defects” are often not known at the time of certification (Structural Substantiation by the Analysis Supported by Test Approach allows an efficient recovery)
Main Points from Analysis Module of 2001 FAA Static Strength Substantiation Workshop

• Base material properties are important to quantifying variability, environmental effects and moduli, but have limited use in predicting static strength

• Composite structural failure usually initiates at local stress concentrations (in-plane or out-of-plane) caused by design detail, damage or manufacturing flaws

• Semi-empirical engineering approaches are typically used to address the many factors that localize damage and affect static strength

• Analysis and test iterations between the various levels of study should be anticipated in developing a complete substantiation of static strength
  – All details, which cause local stress concentration, should be understood to avoid premature failures in component tests
Detailed Outline of Paragraph 8: Proof of Structure – Fatigue/Damage Tolerance

8a Damage Tolerance Evaluation
   1) Damage threat assessment
   2) Structural tests for damage growth
   3) Extent of initially detectable damage
   4) Extent of damage/residual strength
   5) Repeated load testing
   6) Inspection program
   7) Discrete source damage
   8) Environmental effects

8b Fatigue Evaluation

8c Combined Damage Tolerance and Fatigue Evaluation
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

Retained AC 20-107A text from 7a. (1) to (6) and 7b.

Added a new 8a (1) and 8a (5), while renumbering existing sections.

Opening paragraph

- Kept text from opening paragraph of AC 20-107A, 7.
- Updated references to rules (added 14 CFR 23.573a)
- Added text (based on 14 CFR 25.571) on need to avoid catastrophic failure due to fatigue, environmental effects, manufacturing defects, accidental damage
- Added text on component damage tolerance & fatigue tests (coupling with component static strength tests & considerations needed for metal structure)
- Added a reference to use of a building block approach (Section 7b) and a need to consider material & process changes (Appendix 3)

8a. Damage Tolerance Evaluation

(1) Damage threat assessment (new subsection)

- Add text on identification of critical elements and a need for damage threat assessment (words taken directly from the new rule, 14 CFR 29.573)
- Describe considerations for damage threat assessment of a given structure
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation

(1) Damage threat assessment (new subsection), *cont.*

- Described foreign object impact considerations, including impact surveys with configured structure (much of the added text from AC 29-2C, MG8)
- Added text classifying various damage types from a damage threat assessment into five *categories of damage*
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation
   (1) Damage threat assessment (new subsection), cont.
      – Added 1 page description of five categories of damage

8a. Damage Tolerance Evaluation
   (2) Structural tests for damage growth (based on AC 20-107A, 7a. (1))
      – Keeps all text from AC 20-107A, 7a (1)
      – Adds AC 29-2C, MG8 text on inspection intervals for a no growth approach, established considering residual strength of assumed damage.
      – Adds AC 29-2C, MG8 text on slow growth and arrested growth options, including conditions when they are allowed (stable and predictable)
      – Adds text and figures for purposes of clarification (e.g., growth options)
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation
(2) Structural tests for damage growth, cont.
- Figures from 8a. (2)

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Shows Acceptable Interval at reduced RS before being repaired (No-growth case).

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Shows Unacceptable Interval at reduced RS before being repaired (No-growth case).

* Repair to Restore Ultimate Strength
** No growth without repair is not acceptable

Residual strength

Damage initiation or occurrence

Slow-growth approach *

No-growth approach **

Ultimate loads

Limit loads

Time
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation

(2) Structural tests for damage growth, *cont.*

- Figures from 8a. (2)

![Diagram of Damage Tolerance Evaluation](image)

See Figure 4 for an example residual strength curve for the "No Growth" Case.

- Acceptable "No-growth" Inspection Interval for Damage Shown
- Acceptable "Arrested Growth" Inspection Interval for Damage Shown
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation

(3) Extent of initially detectable damage (based on AC 20-107A, 7a. (2))
- Keeps all text from AC 20-107A, 7a (2)
- Added text on the threshold between Category 1 and 2 damage (i.e., inspection methods used by trained inspectors in scheduled maintenance)
- Added text that obvious (Category 3) damage should be detectable by untrained personnel in shorter time intervals

8a. Damage Tolerance Evaluation

(4) Extent of damage/residual strength (based on AC 20-107A, 7a. (3))
- Keeps all text from AC 20-107A, 7a (3)
- Adds words referencing the residual strength requirements for the first four categories of damage
- Adds words on environmental effects and statistical significance
- References special residual strength considerations for bonded joints (6c)
- Covers large damage capability of Category 2 & 3, depending on location
- Promotes same level of fail-safe assurance as metal structure (B-basis link)
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation

(5) Repeated load testing (new subsection)
- Added general text on spectrum load development and truncation of low loads when shown not to contribute (based on AC 29-2C, MG8)
- Added text to cover variability through load enhancement or life scatter factors (based on AC 29-2C, MG8)
- Added text on a need for building block test data to justify load enhancement or life scatter factors used to demonstrate reliability in component tests

8a. Damage Tolerance Evaluation

(6) Inspection program (based on AC 20-107A, 7a. (4))
- Keeps all text from AC 20-107A, 7a (4)
- Adds text to refer back to Figures 4 & 5 as related to unacceptable time intervals for detecting larger no-growth and arrested growth damage sizes
- Discusses difference in inspection intervals for category 2 & 3 damage types
- Discusses a need for expanded inspection of Category 4 and 5 damage types
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation
   (7) Discrete source damage (based on AC 20-107A, 7a. (5))
      – Keeps all text from AC 20-107A, 7a (5)
      – Added thoughts for Category 4 damages, including those requiring specified inspections (e.g., severe in-flight hail)

8a. Damage Tolerance Evaluation
   (8) Environmental effects (based on AC 20-107A, 7a. (6))
      – Keeps all text from AC 20-107A, 7a (6)
      – Added text on a need for more general class of time-related aging when appropriate
      – Added text on the use of environmental knock down factors when appropriate (based on AC 29-2C, MG8)
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8b. Fatigue Evaluation (based on AC 20-107A, 7b.)
  – Removed “(Safe-Life)” from title
  – Keeps all text from AC 20-107A, 7b
  – Added one sentence linking Category 1 damage to this evaluation, including the expectation that ultimate load capability will be retained for the life of the aircraft

8c. Combined Damage Tolerance and Fatigue Evaluation (new section)
  – Added the general need to establish both an inspection interval and service life for critical composite structure (from AC 29-2C, MG8)
  – Implied that there will be a limit to service life (similar to metals)
  – Outline expectations for increasing structural life of composite parts
    Evidence from component repeated load testing
    Fleet leader programs (including NDI and destructive tear-down inspections)
    Appropriate statistical assessments of accidental damage & environmental data
Importance of Linking Damage Tolerance and Maintenance

• One of the main purposes for damage tolerance is to facilitate safe & practical maintenance procedures.

• Findings from the field help improve damage tolerance and maintenance practices in time:
  – Structural safety, damage threat assessments, design criteria, inspection protocol, documented repairs and approved data all benefit from good communications between OEM, operations and maintenance personnel.

• Structural substantiation of damage tolerance, inspection and repair should be integrated.
Progress from Meetings at Airbus (9/05) and Boeing (3/06)

• Boeing and Airbus presented their practices in 3 major areas related to damage tolerance and maintenance
  – Damage tolerance requirements and design criteria
  – Engineering practices for structural substantiation
  – Maintenance practices

• Information summarized in an Excel spreadsheet to directly compare and contrast approaches
# 2006 FAA Composite Damage Tolerance & Maintenance Workshop

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<td><em>Substantiation of Structural Damage Tolerance</em></td>
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<td><strong>Session 4</strong></td>
<td><strong>Session 7</strong></td>
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<td></td>
<td>Break (15 min.)</td>
<td><strong>Substantiation of Maintenance Inspection &amp; Repair Methods</strong></td>
<td><strong>Breakout Team Summary Recap/Actions/Closure/Adjourn</strong></td>
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<td><strong>4th Hour</strong></td>
<td>Lunch (1 Hour)</td>
<td><strong>Session 5</strong></td>
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<td><em>Damage/Defect Types and Inspection Technology</em></td>
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<td><strong>5th Hour</strong></td>
<td>FAA Initiatives Safety Management</td>
<td><strong>Session 6</strong></td>
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<td></td>
<td>Airbus/Boeing/EASA/FAA WG Maintenance Training Update</td>
<td><strong>Technical Breakout Sessions</strong> (<em>Separate working meetings covering technical subjects from Sessions 2 - 5)</em></td>
<td><strong>Session 7</strong></td>
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<tr>
<td><strong>6th Hour</strong></td>
<td>Break (15 min.)</td>
<td><strong>Session 7</strong></td>
<td><strong>Breakout Team Summary Recap/Actions/Closure/Adjourn</strong></td>
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<tr>
<td><strong>7th Hour</strong></td>
<td><strong>Session 1</strong></td>
<td></td>
<td><strong>Chicago, IL, USA</strong></td>
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<tr>
<td></td>
<td><em>Applications &amp; Service Experiences</em></td>
<td><strong>Session 5</strong></td>
<td><strong>July 19-21, 2006</strong></td>
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<tr>
<td><strong>8th Hour</strong></td>
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<td><strong>Session 5</strong></td>
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<td><em>Damage/Defect Types and Inspection Technology</em></td>
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**Chicago, IL, USA**

**July 19-21, 2006**

- **150 Participants**
<table>
<thead>
<tr>
<th>Event</th>
<th>Wednesday, May 9</th>
<th>Thursday, May 10</th>
<th>Friday, May 11</th>
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<tr>
<td><strong>1st Hour</strong></td>
<td>SAE Commercial Aircraft Composite Repair Committee</td>
<td>Session 1</td>
<td>Session 5*</td>
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<tr>
<td><strong>2nd Hour</strong></td>
<td>Overview of Progress &amp; Plans</td>
<td>Applications &amp; Field Experiences (continued)</td>
<td>Field Inspection and Repair QC</td>
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<td>Service History of Composite Structure</td>
<td>Test Standards &amp; Inspector Qualifications</td>
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<td>Service Damage &amp; Reliability of Repairs</td>
<td>Reliable NDI Technology Advances</td>
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<td>Material &amp; Process Controls</td>
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<tr>
<td><strong>Break (15 min.)</strong></td>
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<tr>
<td><strong>3rd Hour</strong></td>
<td>Airbus and Boeing</td>
<td>Session 2*</td>
<td>Session 6</td>
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<td>Perspectives on Safe Industry Practices</td>
<td>Damage Tolerance</td>
<td>Technical Breakout Sessions</td>
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<td>Design Criteria &amp; Objectives</td>
<td>(*Separate working meetings covering technical subjects from Sessions 2 - 5)</td>
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<td>Structural Test Protocol</td>
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<td><strong>4th Hour</strong></td>
<td>Airbus &amp; Boeing (continued) SAE CACRC Active Task</td>
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<td>Group Reports</td>
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<td><strong>Lunch (1 Hour)</strong></td>
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<td><strong>5th Hour</strong></td>
<td>SAE CACRC</td>
<td>Session 3*</td>
<td>Session 7</td>
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<td>Active Task Group Reports</td>
<td>Damage in Sandwich Construction</td>
<td>Breakout Team Summary</td>
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<td>Fluid Ingression</td>
<td>Recap/Actions/Closure/Adjourn</td>
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<td>Growth Mechanisms</td>
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<td>Analysis &amp; Accelerated Tests</td>
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<td><strong>Break (15 min.)</strong></td>
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<tr>
<td><strong>6th Hour</strong></td>
<td>FAA &amp; EASA Initiatives</td>
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<td><strong>7th Hour</strong></td>
<td>FAA &amp; EASA Initiatives (cont.) Recent Progress/Safety</td>
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<td>Management</td>
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<td><strong>8th Hour</strong></td>
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<td>Applications &amp; Field Experiences</td>
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**Amsterdam, Netherlands May 9-11, 2007**

**~110 Participants**
# 2009 FAA/EASA/Industry Composite Damage Tolerance and Maintenance Workshop

**Tokyo, Japan  June 4 & 5, 2009**

<table>
<thead>
<tr>
<th>Thursday, June 4</th>
<th>Friday, June 5</th>
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<tbody>
<tr>
<td><strong>1st Hour</strong></td>
<td><strong>Session 4</strong></td>
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<tr>
<td>FAA Initiatives</td>
<td>Damage Tolerance &amp; Maintenance</td>
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<tr>
<td>Recent Progress/Safety Management</td>
<td>Guidance</td>
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<td>Near- and Long-term Needs</td>
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<td>Design and Process Guidance</td>
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<td>Structural Substantiation = f(application criticality)</td>
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<tr>
<td><strong>2nd Hour</strong></td>
<td><strong>Session 5</strong></td>
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<tr>
<td>EASA Initiatives</td>
<td>CACRC Advances for the Future</td>
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<tr>
<td>Session 1: Applications &amp; Field Experiences</td>
<td>Near and Long-term Initiatives</td>
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<td>Shared Databases and Methods</td>
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<td>Design &amp; Process Guidelines = f(application criticality)</td>
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<td>Break (15 min.)</td>
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<th>3rd Hour</th>
<th>4th Hour</th>
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<th>6th Hour</th>
<th>7th Hour</th>
<th>8th Hour</th>
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<tbody>
<tr>
<td>Session 1: Applications &amp; Field Experiences (continued)</td>
<td>Service History of Critical Composite Structure</td>
<td>Damage Threats &amp; Inspection Strategies</td>
<td>Data for Damage Threat Assessments</td>
<td>Design Criteria &amp; Objectives</td>
<td>Damage Tolerance &amp; Repair Substantiation</td>
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<tr>
<td>Service Damage &amp; Reliability of Repairs (all applications)</td>
<td>Anticipated issues for expanding applications</td>
<td>Test Standards &amp; Inspector Qualifications</td>
<td>Reliable Technology Advances for Inspection</td>
<td>Building Block Approaches (benefits &amp; est. costs)</td>
<td>Structural Test &amp; Analysis Protocol</td>
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<td>Lunch (1 Hour)</td>
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<td>Session 2</td>
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~120 Participants

FAA / CAAs Composite Safety & Certification Meeting
CAA of Singapore, Singapore; Sep 01-04, 2015
Summary of 2006, 2007 & 2009 Workshops

• Critical safety data shared in unique forum of practitioners
• Five *categories of damage* were proposed for damage tolerance and maintenance consideration
  – Integrated efforts in structural substantiation, maintenance and operations interface help ensure complete coverage for safety
• Coordinated inspection, engineering disposition and repair is needed for safe maintenance
  – Actions by operations is essential for detection of critical damage from anomalous events
• FAA is committed to CS&CI with industry, academia and government groups (~370 participants in three workshops)
  – Damage tolerance and maintenance initiatives are active
  – Principles of safety management will be used in future developments (policy, guidance and training)

*Presentations, recaps and breakout session summaries at:* [http://www.niar.wichita.edu/niarworkshops/](http://www.niar.wichita.edu/niarworkshops/)
# Top-Level Agenda for 2011 FAA/EASA/Industry Composite Transport

<table>
<thead>
<tr>
<th>Time</th>
<th>Tuesday, May 17</th>
<th>Wednesday, May 18</th>
<th>Thursday, May 19</th>
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</table>
| 1<sup>st</sup> Hour | **FAA/EASA Composite Safety & Certification Initiatives**  
Background/Plans/Workshop Objectives  
Overview of AC 20-107B & AMC 20-29 in Workshop Areas | **Session 1**  
**Composite/Metal Interface Issues**  
Fatigue & Damage Tolerance Reliability  
Large Scale Static & Fatigue Test Protocol  
Thermal Residual Fatigue Stress Considerations  
Environmental Degradation | **Review Development of FAA Composite Structural Engineering**  
**Safety Awareness Course**  
Evolving Regulations/Special Conditions  
Aircraft Crashworthiness Module |
| 2<sup>nd</sup> Hour | **Break (15 min.)** | **Session 2**  
**High Energy, Wide Area, Blunt Impact**  
Design Criteria & Objectives for Category 2-4  
Category 5 Damage Outside Design Criteria  
Structural Analysis & Test Protocol  
Maintenance/Operations Documentation & Training | **Open Industry Forum**  
Perspectives on Rules, Guidance & Standards Needs  
Composite Structural Crashworthiness Considerations |
| 3<sup>rd</sup> Hour | **Review Development of FAA Composite Structural Engineering**  
**Safety Awareness Course**  
Status of Fatigue & Damage Tolerance  
Sections of the Proof of Structures Module | **Session 3**  
**Damage in Sandwich Construction**  
Problematic Design and Process Details  
Fail Safe Design Features  
Disbond/Core Tearing Growth Mechanisms  
Analysis & Accelerated Tests (GAG, Fluid Ingression) | **Session 5a: Crashworthiness Cert. Protocol**  
Transport Crashworthiness Evaluation  
Building Block Methods |
| Lunch (1 Hour) | Lunch | Lunch (FAA Perspectives on JAMS Research) | Lunch |
| 4<sup>th</sup> Hour | **Review Safety Awareness Course, cont.**  
Status of Maintenance Interface Modules | **Session 4**  
**Bonded Repair Size Limits**  
OEM Structural Substantiation for SRM Repairs  
Structural Substantiation of Repairs Beyond SRM  
Guidelines for Design & Process Definition  
Bonded Repair Fail Safety | **Session 5b: Crashworthiness Cert. Protocol**  
Analytical and Computational Methods  
Analysis Calibration/Validation  
**Industry Perspectives**  
Airbus & Boeing Experiences with Analyses and Tests for Composite Transport Crashworthiness |
| Break (15 min.) | | | |
| 5<sup>th</sup> Hour | **Open Industry Forum**  
Safety Awareness Education Needs  
Composite Industry Designee Qualifications | | |
| 6<sup>th</sup> Hour | **Industry Perspectives**  
Boeing and Airbus Experiences with Composite and Metal Interface Issues (support to Session 1) | | |
| 7<sup>th</sup> Hour | | | |
| 8<sup>th</sup> Hour | **Airline Field Experiences of Relevance to May 18 Sessions** | | |

FAA / CAAs Composite Safety & Certification Meeting  
CAA of Singapore, Singapore; Sep 01-04, 2015
Damage Threat Assessment for Composite Structure

FAR 25.571 Damage Tolerance & Fatigue Evaluation of Structure … must show that catastrophic failure due to fatigue, corrosion, manufacturing defects, or accidental damage will be avoided through the operational life of the airplane.

AC 20-107A Composite Airplane Structure: 7. Proof of Structure – Fatigue/Damage Tolerance (4) … inspection intervals should be established as part of the maintenance program. In selecting such intervals the residual strength level associated with the assumed damages should be considered.
General Structural Design Load and Damage Considerations

For non-detectable and acceptable damage

For detectable damage to be found and repaired through maintenance

For damage occurring with flight crew's knowledge

Design Load Level

Ultimate

1.5 Factor of Safety

Limit

~ Maximum load per lifetime

Allowable Damage Limit (ADL)

Critical Damage Threshold (CDT)

Increasing Damage Severity

Continued safe flight
Composite Fatigue & Damage Tolerance Evaluations

• *Lost Ultimate load capability should be rare* (with safety covered by damage tolerance & practical maintenance methods)

• Fatigue evaluations to ID damage scenarios and demo life

• Damage tolerance evaluations to show sufficient residual strength for damage threats (accidental, fatigue, environmental and discrete source)

• Both fatigue & damage tolerance evaluations support maintenance (*e.g.*, inspection intervals and replacement times)
Repeated Load Response Comparison

![Graph showing comparison between composite and metal behavior over flight hours.]

- Composite Behavior
- Metal Behavior
- B-Basis Life
- Mean Life
- One Life
- Two Lives

Test Limit Stress vs. Life Flight Hours

10^1, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7
Composite Vs. Metal Fatigue Testing

Two notable differences

• Fibrous composite structure is often shown to sustain ultimate load at completion of fatigue testing

• Load enhancement factor generally applied to fatigue spectrum
Key Composite Behavior

- Relative flat S-N curves & large scatter
  - "No-growth" normal fatigue demonstrations
  - Load enhancement factors needed to show reliability
  - Growth options applied conservatively
    - Structure evaluated using growth approach typically has no residual strength problem
    - To demonstrate that loads higher than service are needed for growth
Key Composite Behavior, cont.

• Manufacturing defects and impacts
  – Evaluate complex damage that triggers interactions between interlaminar and translaminar failure modes for *anomalous fatigue* (i.e., *damage tolerance demonstration*)
  – Compression & shear strength affected by damage
  – Similar tensile residual strength behavior to metals
Cycles for Fatigue Testing

“. . . Should be statistically significant, and may be determined by load and/or life considerations”
AC 20-107A, Composite Aircraft Structure, Sec. 7(a)(2)

- 90% probability / 95% confidence (B-basis) level generally acceptable (unless single load path)
- Adjust number of fatigue cycles using load enhancement factor to minimize duration of fatigue testing
- AC 20-107B expands these thoughts to ensure the relevance of load and/or life factors to specific structural detail (material/process & design features)
Load Enhancement Factor Approach

- **PM**: Static Strength
- **PF**: Design Maximum Fatigue Stress
- **PT**: Load Factor
- **ND**: B-Basis
- **NF**: B-Basis

![Graph showing Load Enhancement Factor Approach](chart)

**Maximum Applied Stress** vs. **Repeated-Load Lives**
Load Enhancement & Life Factors
Typical Composite Behavior (B-Basis)

- FAA R&D at Wichita State Univ. has been establishing standards for developing LEF and fatigue load truncation levels
- Details to be documented in CMH-17

\[ \alpha_L = 1.25 \]
\[ \alpha_R = 20.0 \]

Load Enhancement Factor

TEST DURATION (LIFETIMES)

\( n = 1 \)
\( n = 2 \)
\( n = 5 \)
\( n = 10 \)
\( n = 30 \)
Means of Compliance
Damage Considerations

• Rules require catastrophic failure due to fatigue, environmental effects, manufacturing defects or accidental damage to be avoided throughout aircraft operational life

• Draft Part 27 and 29 advisory circular for composite fatigue and damage tolerance outlines damage threat assessments
# Categories of Damage & Defects for Primary Composite Aircraft Structures

<table>
<thead>
<tr>
<th>Category</th>
<th>Examples (not inclusive of all damage types)</th>
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<tbody>
<tr>
<td><strong>Category 1</strong>: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)</td>
<td>Barely visible impact damage (BVID), scratches, gouges, minor environmental damage, and allowable mfg. defects that retain ultimate load for life</td>
</tr>
<tr>
<td><strong>Category 2</strong>: Damage detected by scheduled or directed field inspection @ specified intervals <em>(repair scenario)</em></td>
<td>VID (ranging small to large), deep gouges, mfg. defects/mistakes, major <em>local</em> heat or environmental degradation that retain limit load until found</td>
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<tr>
<td><strong>Category 3</strong>: Obvious damage detected within a few flights by operations focal <em>(repair scenario)</em></td>
<td>Damage obvious to operations in a “walk-around” inspection or due to loss of form/fit/function that must retain limit load until found by operations</td>
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<tr>
<td><strong>Category 4</strong>: Discrete source damage known by pilot to limit flight maneuvers <em>(repair scenario)</em></td>
<td>Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning, exploding gear tires, severe in-flight hail)</td>
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<tr>
<td><strong>Category 5</strong>: Severe damage created by anomalous ground or flight events <em>(repair scenario)</em></td>
<td>Damage occurring due to rare service events or to an extent beyond that considered in design, which must be reported by operations for immediate action</td>
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</tbody>
</table>
**Categories of Damage**

**Category 1:** Allowable damage that may go undetected by scheduled or directed field inspection (or allowable manufacturing defects)

**Category 2:** Damage detected by scheduled or directed field inspection at specified intervals (repair scenario)

---

**Exterior Skin Damage**

**Interior Blade Stringer Damage**
Categories of Damage

**Category 3**: Obvious damage detected within a few flights by operations focal (repair scenario)

**Category 4**: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)

Accidental Damage to Lower Fuselage

Lost Bonded Repair Patch

Rotor Disk Cut Through the Aircraft Fuselage Belly and Wing Center Section to Reach Opposite Engine

Severe Rudder Lightning Damage

Allowable Damage Limit (ADL) vs. Critical Damage Threshold (CDT)
Categories of Damage

**Category 5**: Severe damage created by anomalous ground or flight events (repair scenario)

- **Birdstrike (flock)**
- **Birdstrike (big bird)**
- **Maintenance Jacking Incident**
- **Propeller Mishap**
Factors Affecting Placement of Damage Threats in Categories

- Design requirements, objectives and criteria
- Structural design capability
  - Impact damage resistance
  - Detectability of different damage threats
  - Residual strength
  - Damage growth characteristics
- Inspection methods
  - Visual detection methods ➔ generally larger damage sizes
  - NDI ➔ needed if Category 2 damage can’t be visually detected
- Other considerations: service experience, costs, customer satisfaction and workforce training
Complexities of Foreign Object Impact

Factors critical to type and extent of damage, as well as its detectability. Note there were many interactions, which were as important as the main effects.

Factors Affecting Placement of Damage Threats in Categories

Foreign-Object Impact is Complex

1 in. dia. impactor

3 in. dia. impactor

Some NDI may be needed to place damage at the left into Category 2
Typical Industry Interface Relating to AC 20-107B and CMH-17 V3 CH 12 (Rev. G)

Impact damage visibility is a strong function of impactor size & shape

Shape of residual strength curve is important to damage tolerance
Typical Industry Interface Relating to AC 20-107B and CMH-17 V3 CH 12 (Rev. G)

Tensile strength (small notch) versus toughness (large notch) trades

Laminate thickness effect for notched compressive strength
Other Factors Affecting Placement of Damage Threats in Categories

- Effects of real-time aging and long term environmental degradation could lead to life limits lower than substantiated using repeated load tests.
- Failsafe design considerations may be needed to place large hidden damage into Category 2 (e.g., *large hidden damage requiring internal visual inspection*)
  - Bonded joints
  - Broken elements
- Category 3, 4 and 5 damages generally require special inspections of structural elements near obvious damage (e.g., *remote points reacting high energy impact forces*)
Environmental & Accidental Damage *Damage Threat Assessment*

Not easily derived for new composite structure

- Metal has relied on service experience
- Selection of impact damage locations difficult when following a “certification by test approach”
  - Seek areas of bonded structure attachment and termination
  - Rely on results from “impact surveys” to determine most critical (least detectable, most severe)
- Conservative engineering judgment, fail-safety and large damage assumptions help overcome lack of service experience
Environmental & Accidental Damage

Damage Threat Assessment, cont.

• Operational awareness and updates encouraged
  – How to share critical damage threats with operations personnel?
  – Damage threat assumptions that prove to be unconservative require action (near and long-term solutions)
Means of Compliance
Structural Substantiation Options

• Flaw tolerance/safe life
  Demonstrate ultimate load capability after fatigue life
  – For selected damage (Category 1) and/or structure not requiring inspection

Outcome: reliable demonstration of replacement time
Means of Compliance
Structural Substantiation Options, cont.

• Damage tolerance options
  No-growth: inspection interval dependent on arrested damage size
  Slow growth: similar to metal fracture mechanics in application
  Arrested growth: inspection interval dependent on arrested damage size

Outcome: reliable demonstration of inspection intervals
AC 20-107B
Para. 8: Proof of Structure – Fatigue & DT

• Efforts to link/clarify language found in composite rules and guidance
  – Avoid catastrophic failure due to fatigue, environmental effects, manufacturing defects, accidental damage
  – Applicant responsible for damage threat assessment of specific applications

• No-growth, slow growth and arrested growth options

• Standard impacts for small damage used in demonstrating Ultimate load capability

• Large damage capability for rare damage threats
  – Readily detected by operations
  – Providing coverage for the complex nature of some impact events that yield severe but less detectable damage

• Inspection considerations for different damage threats
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation
(2) Structural tests for damage growth
  – Figures from 8a. (2)

- Residual strength
- Damage initiation or occurrence
- Slow-growth approach *
- No-growth approach **
- Ultimate loads
- Limit loads
- Time

* Repair to Restore Ultimate Strength
** No growth without repair is not acceptable

-- Shows Acceptable Interval at reduced RS before being repaired (No-growth case).
——— Shows Unacceptable Interval at reduced RS before being repaired (No-growth case).
Means of Compliance

Structural Substantiation Options, cont.

• Combined options
  – Used for different damage threats (categories of damage) considered for the same structure

Primary outcomes: reliable demonstration of inspection interval for detectable damage and replacement time for non-detectable damage
Para. 9: Proof of Structure – Flutter and Other Aeroelastic Instabilities

Expanded title to include “other aeroelastic instabilities”
Kept much of the text from AC 20-107A, paragraph 8

Added text to outline flutter considerations and other aeroelastic evaluations (non-composite specific)
– Added words to ensure adequate tolerance for quantities affecting flutter
– Added general words on aeroelastic evaluations that are needed
Para. 9: Proof of Structure – Flutter and Other Aeroelastic Instabilities (Cont.)

Added text for composite structure evaluation

- Add words to consider the effects of large Category 3 and 4 damage and potential mass increase for sandwich panel water ingressions
- Emphasized that composite control surfaces may be prone to accidental damage & environmental degradation
- Added words on concerns for a) weight & stiffness changes due to repair or multiple layers of paint and b) structures in proximity of heat sources
Potential Flutter Problems with Minimum Gage Control Surfaces or other “Critical Structures”

- Lower loads on some control surfaces and large “critical” secondary structures (i.e., residual strength is not in question)
  - Minimum gage structures have individual layers critical to torsion and bending stiffness
  - Layers of safety management needed for continued airworthiness \(\Rightarrow\) direct link to OEM data, maintenance experiences & operations awareness
  - Limits of damage tolerance design criteria and related maintenance procedures must be understood by operations (their vital safety role)
Potential Flutter Problems with Minimum Gage Control Surfaces or other “Critical Structures”

- Highlights of Airbus presentations from 2009 FAA Workshop in Tokyo, Japan
  1. Airbus shared essential safety data on a rare composite growth phenomena (root cause and engineering solution) not previously available
  2. minimum-gage sandwich disbond growth under GAG cycles [Growth rates = f (disbond size)]
  3. Potential bonded repair problem (see below)

- Air Transat Flight 961
  - Blunt Impact of Sandwich Part With Sharp Penetration Near Center
  - Followed by Poorly Bonded Repair Patch to Penetration Zone Only

- New CMH-17 Disbond & Delam TG Initiative
Para. 10: Continued Airworthiness

New paragraph, including content from AC 20-107A 9g and 9h.

Introductory statements that repaired composite structures shall meet all other requirements covered in this AC

10a. Design for Maintenance (new subsection)
- Text on design to allow access for repair and inspection in field maintenance environment
- Repair documentation should recognize inspection/repair issues and training for critical damage difficult to detect, characterize and repair
- Document inspection intervals, life limits and levels of damage to a part that will not allow repair (requiring replacement)

10b. Maintenance Practices (new subsection with three parts)
- Opening statement taken from AC 20-107A, 9g.
- Identifies the need for maintenance, inspection, and repair documentation because “standard practices” are not common (using examples of jacking, disassembly, handling, and part drying methods)
- Three parts include: (1) Damage Detection, (2) Inspection, (3) Repair
Para. 10: Continued Airworthiness


- (1) Damage Detection. Describes links between damage tolerance substantiation and procedures for detecting degradation in structural integrity and protection of structure (incl. degradation in lightning protection system as related to structural integrity, fuel tank safety and electrical systems)
- (1) Damage Detection. Details on considerations for visual methods used in damage detection (lighting conditions, inspector eye sight standards, dent depth relaxation, and surface color, finish & cleanliness)
- (2) Inspection. Discusses the general difference between damage detection methods and inspection procedures used to characterize damage and perform a repair (both in-process & post-process)
- (2) Inspection. Describes the need for substantiation of in-process & post-process inspection procedures
- (2) Inspection. Describes design considerations for bonded repairs, which require same level of structural redundancy as base structure
Para. 10: Continued Airworthiness


- (3) Repair. Describes need for substantiation of bonded & bolted repairs, (incl. replacement of protective surface layers and lightning strike protection)
- (3) Repair. Outlines safety issues (bond material compatibilities, bond surface prep, cure thermal management, composite machining, special composite fasteners & installation techniques, and in-process controls)
- (4) Repair. Describes the need for repair records for subsequent maintenance actions
- (4) Repair. Recommends reporting of service difficulties, damage and degradation for continuous updates on damage threat assessments (support updates to design criteria, analysis & test databases) and future design detail & process improvements

10c. Substantiation of Repair, (new subsection)

- Opening statement taken from AC 20-107A, 9h.
- Outlines a need for documentation on Allowable Damage Limits (ADL) and Repairable Damage Limits (RDL)
- Limits on bonded repair (per redundancy considerations outlined in section 6c)
Para. 10: Continued Airworthiness

10c. Substantiation of Repair, (new subsection), cont.
- Describes additional substantiation data needs for damage types and sizes not considered in development (as related to damage tolerance and repair)
- Warning for MRO and airlines to work with OEM for major composite repair and alteration due to significant data needs for certificated repair design and process substantiation

10d. Damage Detection, Inspection & Repair Competency, (new subsection)
- Ref. SAE AIR 5719 on training for awareness of safety issues in composite maintenance and repair (but notes it is not for specific “skill-building”)
- Describes the need for technician, inspector and engineering training on the skills necessary for damage disposition and repair
- Describes the need to train pilots, line maintenance, and other operations personnel to be aware of anomalous ground service and flight events, which may create critical damage not covered by design or scheduled maintenance (i.e., need for immediate reporting and likely expanded inspections beyond those covered in the SRM)
Integration of Composite Maintenance and Damage Tolerance

- Early development of maintenance procedures
- Efficient, low-cost NDI procedures to locate damage (that always find CDT)
- Reliable and simple NDE to quantify effects of damage
- Cost-effective repair with minimal down time when damage is found

**Design for Repair**

- Well-defined ADL

**Ultimate Limit**
- Maximum load per fleet lifetime
- Continued safe flight

**Allowable Damage Limit (ADL)**

**Critical Damage Threshold (CDT)**

**Increasing Damage Size**

Importance of Both In-Process and Post-Process Inspections for Composite Repair

- Some composite repair details cannot be reliably verified by practical post-process inspections
  - Poorly formed adhesion (i.e., weak bonds)
  - Ply layup and stacking sequence
  - Use of qualified materials and processes

- In-Process and post-process inspections provide the necessary and nearly “fail-safe” conditions for reliable composite repairs (bonded & bolted)
Case Study Example: Transport Flap Assembly

An airline received an overhauled flap assembly and observed that the assembly would not properly fit due to contour, requiring further investigation.

Weighted on one side, contour had 1.5 inch gap.
Case Study Example: Transport Flap Assembly

Further investigation after removing lower skin and honeycomb revealed improper practices

Incorrect film adhesive (SRM limits to 6 inches)

Improper use/location of thermocouples resulted in overheating
Case Study Example: Transport Flap Assembly

*Further investigation after removing lower skin and honeycomb revealed improper practices*

Utilizing tooling with incorrect contours, during the repair, caused a warp condition on the spar.
# Completed Case Studies

<table>
<thead>
<tr>
<th>Component</th>
<th>Improper Repair Practices</th>
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<tbody>
<tr>
<td><strong>Flap</strong></td>
<td>1. Tooling had incorrect contours&lt;br&gt;2. Repair outside of SRM limitations&lt;br&gt;3. Incorrect hot bonder technique</td>
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<tr>
<td><strong>Slat</strong></td>
<td>1. Tooling had incorrect contours&lt;br&gt;2. Repair design based on superseded flag note</td>
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<tr>
<td><strong>Inboard Flap</strong></td>
<td>1. Repair station did not utilize bond-line confirmation (verifilm) as required by operator engineering&lt;br&gt;2. Excessive bond thicknesses suggesting incorrect tool contour&lt;br&gt;3. Damaged core from over-heating&lt;br&gt;4. Distorted honeycomb replacement core</td>
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<tr>
<td><strong>Outboard Flap (Metal Bond)</strong></td>
<td>1. Repair procedure alternative (PAA) utilized instead of HF/Alodine in a procedure which was not approved by the OEM or operator&lt;br&gt;2. Improper use of FAA Form 8130-3 approved procedure listing HF/Alodine ‘whenever PAA not convenient’</td>
</tr>
<tr>
<td><strong>Nose Cowl</strong></td>
<td>1. Repair outside of SRM limitations&lt;br&gt;2. Improper repair technique and use of materials which appeared to conceal discrepancies</td>
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</table>
Not all damaging events (e.g., severe vehicle collisions) can be covered in design & scheduled maintenance

- Safety must be protected for severe accidental damage outside the scope of design (defined as Category 5 damage) by operations reporting
- Awareness and a “No-Blame” reporting mentality is needed
- Category 5 damage requirements:
  a) damage is *obvious* (e.g., clearly visual) and *reported* &/or
  b) damage is *readily detectable* by required pre-flight checks &/or
  c) the *event* causing the damage is otherwise *self-evident* and *reported*
    e.g., obvious, severe impact force felt in a vehicle collision
Our Tenth Anniversary Year Studying a Key Area
HEWABI = High Energy Wide Area Blunt Impact

- According to comments on Flightaware:
  Occurred March 23 2014, UPS Boeing 757-200 (N462UP) on Spot 90 at the Miami International Airport Repaired by AAR Aircraft Services Miami, and returned to flight status on April 13.

  The truck belongs to a catering company. It was being driven by a female who was not supposed to be driving, hence the reason they jumped out and switched really quick.

  The passenger told security he was the driver, but once they reviewed this footage they saw he clearly wasn’t. They were both fired.

http://youtu.be/SLd-qw6bCRw
Damage is not always visually obvious…
*e.g.*, *service vehicle collision with fuselage*

even in metallic Structures as shown here.

How would such high energy manifest itself in damage to a composite fuselage??
“Absolutely terrifying” flight after ground-crew mistake

PLANE MAKES EMERGENCY RETURN TO SEA-TAC

Baggage handlers blamed for gash in jet’s side

BY JENNIFER SULLIVAN
AND MELISSA ALLISON
Seattle Times staff reporters

Alaska Airlines Flight 536 was 20 minutes out of Seattle and
heading for Burbank, Calif., Monday afternoon when a thun-
derous blast rocked the plane.
Passengers gasped for air and grabbed their oxygen masks as
the plane dropped from about 26,000 feet, passenger Jeremy
Hermanns said by phone Tues-
day.
“This was absolutely terrifying
for a few moments,” said Herm-
manns, 28, of Los Angeles. “Bas-
ically your ears popped, there’s a
really loud bang and there was a
lot of white noise. It was like
somebody turn-
er in your ear.”
Though the quickly stabil-
sers spent
utes tearful an-
tried odor of
overwhelmed
manns said.
“A lot of p

She said Alaska conducted

safety briefings with employees

at Sea-Tac on Tuesday “to dis-
cuss the importance of rapid

and thorough reporting of any

ground incidents, whether

there is apparent aircraft dam-
age or not.”

The airline also is reviewing
details from Monday’s incident

with the NTSB and working

with the agency to ensure air-
craft safety, she said.
Problem Definition: Awareness by Operations and Service Personnel Involved in a “Severe Vehicle Collision”

• How to provide awareness training
  – What is their current level of education?
  – What is the anticipated attention level?
  – How to ensure they don’t act as qualified inspectors?
  – Worried about losing their job if they report their mistake?

• What can the OEM do to minimize the problem
  – Robust design criteria for impact damage resistance (i.e., set the level of “severe vehicle collision” high)
  – Personnel in positions of responsibility need education on what levels of vehicle collision impact will cause damage beyond that protected by scheduled maintenance and existing source documentation
### Solution Path for Vehicle Collisions Classified as Category 5 Damage

Layers of Safety Management are needed
- Damaging events outside the scope of those considered in design must be of a magnitude that ensures reporting (*i.e.*, design to sufficient impact damage resistance and damage tolerance)
- Simple training is needed to ensure the essential “reporting” role of operations and aircraft service personnel without blame
- Source documentation and training for line maintenance, inspectors and structural engineers needed to disposition such events to ensure proper application of conditional inspection and repair procedures
- Practical NDE methods should be able to detect critical levels of damage

<table>
<thead>
<tr>
<th>1) Impact Event is Reported</th>
<th>Awareness by ground crews, service crews, air crews, and/or ramp personnel</th>
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<tr>
<td>2) Line Maintenance Ensures Proper Evaluation</td>
<td>Line and Dispatch personnel trained to seek skilled disposition assistance</td>
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</table>
| 3) Engineering Evaluation & Repair (if necessary) | a. Engineers, OEM, technicians, inspectors with proper training  
b. Allowable Surface Damage Limits do **NOT** apply  
c. Initial inspection is to detect **MAJOR** internal damage |
Conditional Inspections and Disposition

• Aircraft Maintenance Manual (AMM) should contain instructions for conditional inspections to be performed following a vehicle collision
  – Exterior instrumented NDI at point of contact and adjacent supporting structure will be needed
  – Interior detailed visual inspection will also help determine the severity of the damage (e.g., broken frames or stiffening elements, significant debonding, etc.)

• Disposition of damage and repair may be beyond the procedures documented in the structural repair manual (SRM)
  – Additional structural design and process substantiation may be needed (i.e., combination of analysis and tests to address fatigue, damage tolerance, static strength, etc.)
• New R&D started to help bound important variables and worst case scenarios (i.e., most severe internal damage with least exterior visually detectable indications)

• Both analysis and test evaluations are planned
  – Vehicle collision characteristics (e.g., speed, angle of incident, impactor geometry/material and structural location) important to:
    a) damage severity,
    b) details worth reporting,
    c) possible visual evidence and
    d) identification of inspection needs (coordinated with M&I TCRG)

*Dr. Hyonny Kim, UCSD*
Para. 11. Additional Considerations

Paragraph 11 (Updated section that used to be paragraph 9)
– Text from AC 20-107A, Sections 9d, 9e, 9f, 9g, and 9h all moved to AC 20-107B Section 6 and 10

11 a. Crashworthiness (Renamed)
– AC 20-107A content in the subsection entitled “Impact Dynamics” was effectively captured in new text
– New content has a basis in special conditions recently developed for composite transport fuselage crashworthiness
  ➢ Recognizing differences between unique rules for each aircraft product type (more considerations for transport airplanes & rotorcraft)
  ➢ Realistic and survivable crash impact conditions seeking equivalent levels of safety with comparable metal aircraft types
  ➢ Allowance for an approach using analysis supported by test evidence

Content increased from 1.25 to 5 pages
Para. 11a: Crashworthiness, cont.

- Four main criteria areas to contrast composite & metal aircraft structure
  - Protection from release of items of mass
  - Emergency egress paths must remain
  - Accelerations and loads at seat locations must not exceed critical thresholds
  - Survivable volume must be retained
- Outlines a need for transport airplane fuel tank structural integrity for a survivable crash as related to fire safety
- Lists considerations for valid analyses and test evidence used in making a comparison of metal and composite crashworthiness
  - Comparative assessments for a range of aircraft loading and crash conditions
  - A need to consider analysis sensitivity to modeling parameters
  - Realistic simulation of structural behavior, including progressive failure
  - Factors affecting dynamic test measurements

- Note that an industry WG has been assembled to address the development of more definitive guidance
Para. 11: Additional Considerations

11 b. Fire Protection, Flammability and Thermal Issues (Renamed)

- AC 20-107A content under (1) in the subsection entitled “Flammability” was effectively captured in new text
- Recognizes differences between unique rules for each aircraft product type
- Obsolete info in AC 20-107A (2) was removed [and a footnote was added to indicate AC 20-107B does not cover rules and guidance materials for aircraft interiors and baggage compartments]
- Background on traditional flammability safety concerns (firewalls, engine mounts and other powerplant structures), with discussion of new issues for expanded use of composites in transport wing and fuselage structures
  - In-flight cabin fire protection and the role of composite airframe structure
  - Exterior fire protection after crash landings: fuel-fed fire exposures for fuselage and wing structures (time for passenger egress & fuel tank fire safety issues)
- Likely need for special conditions to outline expectations
  - In-flight fire protection: use of composite structures should not add to in-flight fire hazards (release of toxic gas, fire progression) vs. existing metal structures
  - Post-crash fire protection: exterior fuel-fed fire exposure should allow the same level of safe passenger egress (toxic gas, burn-through) as existing metal structure
Para. 11: Additional Considerations


– New content on thermal issues for composite structure exposed to high temperatures

- List of potential sources of high temperature (failed systems, engine and interior fires)
- Description of irreversible heat damage as related to thresholds in composite material properties (glass transition temperatures)
- Need for special inspections, tests and analyses to determine the airworthiness of structures exposed to high temperatures (inspection data defining damage metrics for disposition)
Para. 11: Additional Considerations

11 c. Lightning Protection.

- AC 20-107A content in the subsection by the same name was effectively captured in new text [(1) appears in various subsections of 10c. and (2) was captured in 9b.(1)]

- Opening Paragraph outlining issues related to composite structures
  - Substantiation by tests (industry standards)
  - Dependent on lightning protection zone designated for specific parts of aircraft
  - Evaluation of repairs to lightning protection system
  - References to other AC, policy, FAA Handbook (which references other technical guidance and industry standards)

- **(1) Lightning Protection for Structural Integrity.**
  - Describes technical issues and typical design features needed (mesh, wires, electrical bonding)
  - Structural damage in lightning tests noted to Category 1, 2 or 3, depending on level of detection
  - References to other AC and policy (which references other technical guidance and industry standards)
Para. 11: Additional Considerations

11 c. Lightning Protection, *Cont.*

- (2) *Lightning Protection for Fuel Systems.*
  - Eliminate structural penetration, arcing, sparks or other ignition sources
  - Transport airplane regulations (CFR 25.981)
  - List of typical design features needed
    (mesh, joints, fasteners and support to fuel system plumbing)
  - References to other AC and policy (which reference other technical guidance and industry standards)

- (3) *Lightning Protection for Electrical and Electronic Systems.*
  - Physical description of the issues
  - List of typical design features needed (mesh, foil & electrical bonding)
  - References to AC (which references other technical guidance and industry standards)
Considerable Differences in Appropriate Regulations for Crashworthiness

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Initial Guidance Needs for Current Transport Special Conditions

- Improve wording in special conditions (interpretation of language, e.g., during CAA validation)
- Lumbar and femur load analysis interpretations in guidance (since we are focused on vertical loads, femur loads are unimportant)
- Baseline what “equivalence” means for the four criteria subjected to multiple aircraft cargo and passenger loading conditions
- What are the important parameters to characterize in meeting the four criteria as related to the overall safety of the aircraft
- Practical bounds on aircraft cargo and passenger loading conditions for evaluation (See UW and WiSU parametric studies)
- Outline general considerations in defining building block analysis and test correlation for varying hybrid composite/metal designs*
- Rationale expectations for establishing test calibration and demonstrating validation* (e.g., UW and WiSU R&D)
- Guidelines for dynamic modeling simulations, including material model standardization*

*also see ongoing CMH-17 integration efforts (airplane-level digital twins)
Initial Guidance Needs for Current Transport Special Conditions

- Analysis calibrations (including specific failure modes, energy absorption, strain rates) will have limits vs testing limits/bounds*
- Training and mentoring needs for dynamic structural models (Level II Safety Awareness for certification oversight versus Level III practitioners)
- Scaling issues in moving from business to regional jet sized aircraft

* also see ongoing CMH-17 integration efforts (airplane level digital twins)

Thoughts beyond the title of this chart
- Clarification of hard landings versus crash conditions will help future crashworthiness efforts
- A need to include ditching considerations before the more generic rulemaking discussed by Joseph P.
- Rulemaking needs may be identified through the course of developing more guidelines, policy and guidance for existing special conditions – at any rate, it should be based on such efforts
CMH–17 CW Working Group Organization

Working Group is divided in three Task Groups, each focusing on a specific aspect of crashworthiness

- **Crashworthiness Working Group**
  - Allan Abramowitz (FAA)
  - Mostafa Rassian (Boeing R&T)

- **Crash. Certification Protocol Task Group**
  - Joseph Pellettiere (FAA)
  - Kevin Davis (Boeing Commercial)
  - Michel Mahe (Airbus)

- **Crash. Analysis Guidelines Task Group**
  - Mostafa Rassian (Boeing R&T)
  - ???

- **Crash. Test Methods Group**
  - Dan Adams (Univ. of Utah)
  - ????
Considerable Differences in Appropriate Regulations for Fire Safety

<table>
<thead>
<tr>
<th>Fire Safety Regulations</th>
<th>Part 23</th>
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Composite Burn & Toxic Gas Issues

- See TAD for special conditions & issue papers applied to transport aircraft with extensive composite fuselage and wing applications
  - Cabin safety experts have relied heavily on demonstration of equivalent levels of safety (metal versus composites)
- Fire safety experts at FAA Technical Center (e.g., Dick Hill) helped define realistic structural testing
- Industry has relied on system/design solutions instead of advanced, more fireproof resins
Appendices 1-3

Appendix 1*. Applicable Regulations and Relevant Guidance
- Starting with harmonized table of rules created for CMH-17 Vol. 3/Ch. 3
- Removed rules for flammability of interiors and baggage compartments
- Updated applicable regulations to current
- Includes a list of applicable composite guidance
  (AC and Policy Statements)

Appendix 2*. Definitions
- Plans to update (link to standards groups: SAE CACRC, ASTM & CMH-17)

Appendix 3*. Change of Composite Material and/or Process
- Based on updates to EASA CS 25.603, AMC No. 1, Para. 9 and No. 2
Appendix 1: Applicable Regulations and Relevant Guidance

1. Applicable Regulations
   - “A list of applicable regulations is provided for subjects covered in this AC. In most cases, these regulations apply regardless of the type of materials used in aircraft structures.”
   - Footnotes
     - Disclaimer (1): “This list may not be all inclusive and there may be differences between regulatory authorities.”
     - Disclaimer (2): “Special conditions may be issued for novel and unusual design features (e.g., new composite materials systems).

2. Guidance
   - Brief description of purpose of AC and PS as guidance
   - “The guidance listed below is deemed supportive to the purposes of this Advisory Circular.”
Appendix 2: Definitions

• Maintained list from AC 20-107A
  – Will update as needed to be consistent with major standards groups
  – Eliminated “laminate level design values or allowables”, “lamina level material properties”, and “flaw”

• Additional terms
  – Anisotropic
  – Heterogeneous
  – Critical Structure
  – Primary Structure
  – Disbond (same as debond)
  – Structural Bonding
  – Intrinsic Flaw
  – Overload Factor
  – Load Enhancement Factor (LEF)
  – Category of Damage
  – Weak Bond
  – Debond
  – Delamination
  – No Growth Approach
  – Slow Growth Approach
  – Arrested Growth Approach

• Purpose was to include any terms used in AC 20-107B that may cause confusion for readers.
Appendix 3: Change of Composite Material and/or Process

• Started with EASA AMC No. 2 to 25.603
  – Generally reduced size to account for thoughts already captured in previous parts of AC 20-107B

• Title changed to “Change of Composite Material and/or Process”

• Updated the appendix purpose:
  – “This appendix covers material and/or process changes, but does not address other changes to design (e.g., geometry, loading).”

• Highlights the need for testing at multiple building block scales

• Provides an update to three classes of material or process change, including examples.

• Added links to previous sections of AC 20-107B and references

• Removed table & figure from EASA AMC No. 2 to 25.603