AC 20-107B Content Review

With focus in selected areas

- *Development of AC 20-107B*
- *AC 20-107B content highlights*
  - ➢ *Material & Fabrication Development with a focus on bonded structure*
  - ➢ *Fatigue & damage tolerance*
  - ➢ *Continued operational safety*

Larry Ilcewicz

Lester Cheng

Wellington, New Zealand
March 01-04, 2016

“Composite Safety Meeting & Workshop” - Development of AC 20-107B -

- Background – Products & Certification
- Update Justification & Knowledge Basis
- AC Content Development
- Review Processes & Issuance
- Post AC 20-107B Activities

Background - Composite Aircraft Structures

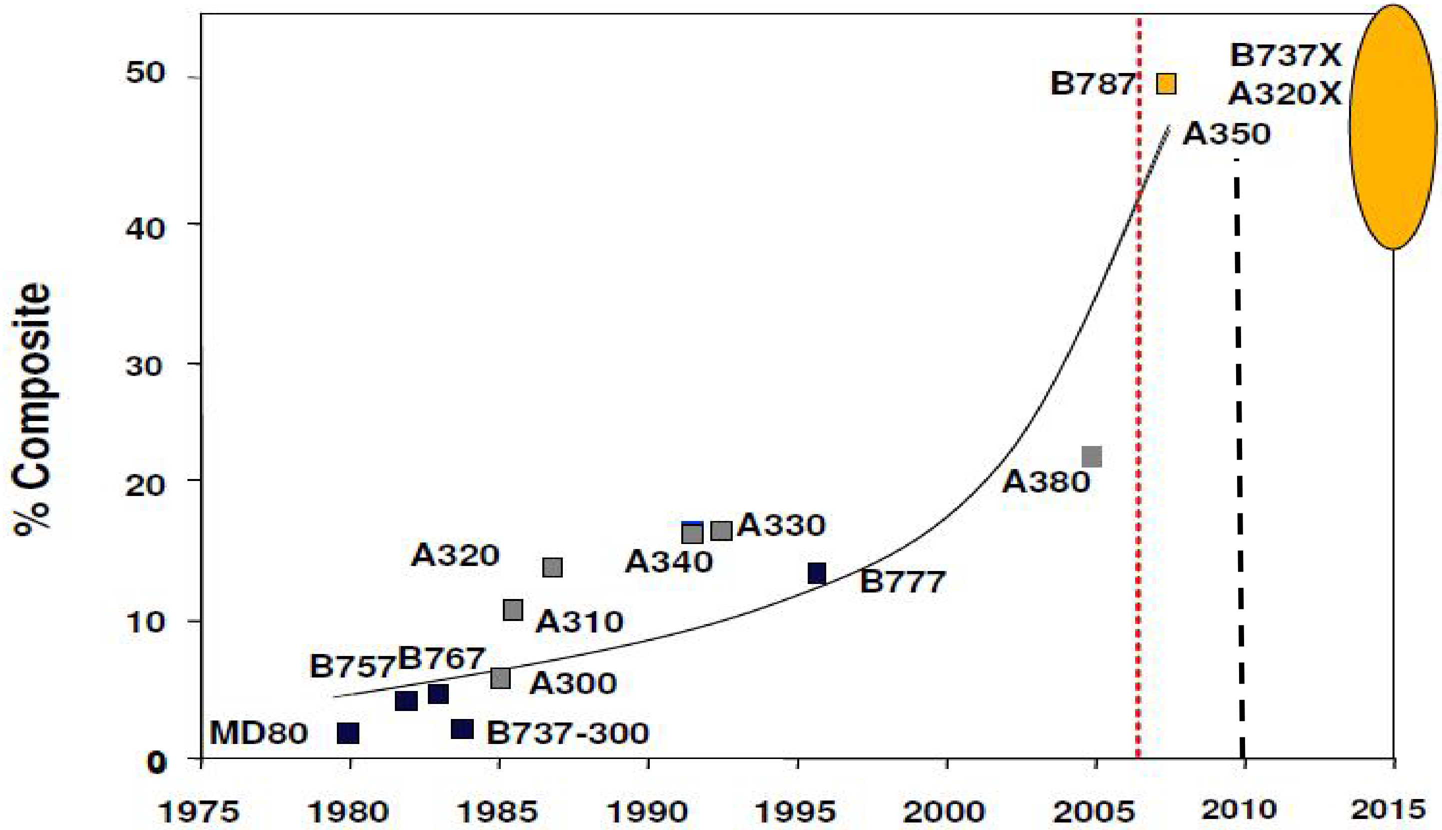
Transport Aircraft

- Secondary structure
- Control Surfaces
- Empennage
- Wing & fuselage applications for new aircraft
- Some engine (e.g., fan blades)

Small Airplanes and Rotorcraft

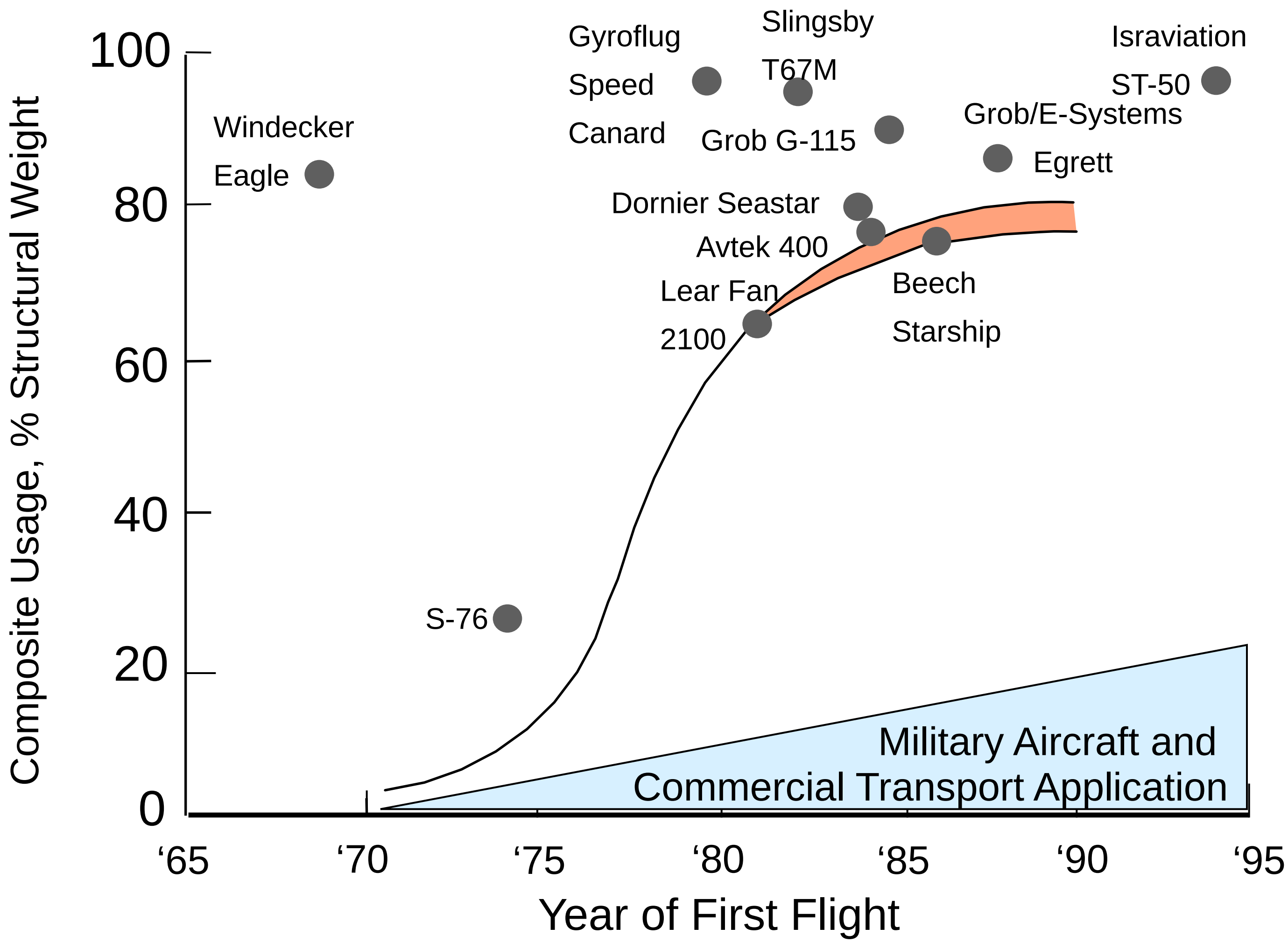
- Most structures
  - Pressurized fuselage
  - Wing
- Dynamic components
  - Propellers & rotor blades
- Extensive bonding

Transport Composite Usage



Note that chart is inaccurate beyond 2007, as recent programs didn't start or finish as originally planned (resource dilution, lack of development readiness/certification efficiency or all of the above)

Implementation of Composites in Small Airplane and Rotorcraft Applications



Background - State of the Industry

- **Situation**
  - Composites have traditionally offered advantages due to fatigue & corrosion resistance, weight savings and other aircraft performance advantages (aero shape, larger cutouts)
  - More recently, the additional advantages from manufacturing cost savings, customer comfort interests & damage tolerance are driving more applications
- **Composite applications are expanding faster than the qualified workforce involved in structural engineering, manufacturing and maintenance functions.**
- **Technical concerns driving Safety Management:**
  - Composites are a non-standard technology
  - Limited shared databases, methods, guidance
  - Small companies have limited resources and certification experience
  - "Big-brother" (military development/standardization) expectations have gone away

Background - AC 20-107A vs. Certification Practices

- **Much of AC 20-107A is still valid**
  - Benchmark for general composite guidance
  - More definitive guidance had been developed to fill needs (for aircraft types and specific technical issues)
  - It contained some complex/difficult wording for new users
- **Service safety problems and/or certification experiences have not forced a need for change**
  - No accidents or industry groups have suggested a need for change or update
  - General nature of the document was not a constraint on the industry pursuing new technology

Agreement from AASC/AECMA Specialists Group on Draft AC 20-107A "Composite Aircraft Structure"

Issued on 4/25/1984

5. It is agreed by all that this joint effort has been mutually beneficial, that this level of cooperation should be considered in other technical areas, and that this group should be reconstituted in no more than five years to update the guidance material to reflect technology developments.

J. Soderquist
Federal Aviation Administration

D.S. Warren
Mc Donnell Douglas Aircraft Company

J. McCarthy
Boeing Commercial Airplane Company

A.M. James
Lockheed-California Company

J.W. Bristow
Civil Aviation Authority

L. Baranes
Service Technique des Programmes Aéronautiques

D. Chaumette
Avions Marcel Dassault-Breguet Aviation

T.W. Coombe
British Aerospace Aircraft Group

J.F. van der Spek
Rijksluchtvaartdienst

Review of “Composite Aircraft Structure” AC
Participants: Gatwick (UK) Meeting (March/2003)

- **CAA (UK)**
  - John Bristow
  - Simon Waite
  - Richard Minter
- **CEAT (French, JAA Composite Specialist)**
  - Jean Rouchon
- **ENAC (Italian)**
  - Bruno Moitre
- **FAA (US)**
  - Larry Ilcewicz

Summary from Review of "Composite Aircraft Structure" AC

Gatwick (UK) Meeting (March/2003)

- All participants agreed on a need for revision
  - Harmonization with ACJ 25.603 (AMC No. 1 to CS 25.603)
  - Remove obsolete guidance
  - Working group should include industry and regulatory composite experts
- Strategy to retain this AC as a "general composite guidance"
  - Agree that other more definitive guidance is also needed as industry standards evolve

Summary from Review of "Composite Aircraft Structure" AC

Gatwick (UK) Meeting (March/2003) (Cont.)

- Technical areas that need update or change
  - Damage tolerance (impact scenarios, composite/metal interface, scatter factors, fatigue spectra, test substantiation, product types)
  - Environmental conditioning & test substantiation
  - Structural bonding (weak bond issues)
  - Maintenance, inspection and repair
  - Flammability & crashworthiness
  - Recognize new materials and manufacturing processes
  - Composite specialist training needs
  - *More definitive guidance is also needed in above areas*
- *Gatwick inputs formed initial basis for FAA plan.*

Copy of March 2003 Meeting Minutes are available from L. Ilcewicz upon request

CS&CI Knowledge Base
- Milestone Achieved -

- Policy/training for base **material qualification & equivalency** testing for shared databases (update 2003)*
- Policy/training for **static strength substantiation** (2001)
- New rule & AC for **damage tolerance & fatigue evaluation** of composite rotorcraft structure (2002, 2005 & 2009 releases)
- AC for **material procurement & process** specs (2003)*
- Technical document on **composite certification roadmap** (2003)

* FAA Technical Center reports exist for detailed background on engineering practices

CS&CI Knowledge Base
- Milestone Achieved -

- Policy on substantiation of secondary structures (2005)
- Policy for bonded joints & structures was released (2005)*
- Tech. document on composite maintenance & repair (2006)
- Composite maintenance & repair awareness training (2008)*
- Support of CMH-17 (since 1999)
  - New CMH-17 V3/C3: Aircraft Structure Certification and Compliance
  - Updates to CMH-17 V3, C 12-14 in areas of DT & Maintenance
  - CMH-17 tutorials initiated in 2007

* FAA Technical Center reports exist for detailed background on engineering practices

Links with CMH-17, SAE CACRC and Safety Management

- **Composite Materials Handbook (CMH-17)**
  - ~ 100 industry engineers meet every 8-9 months
  - Airbus/Boeing/EASA/FAA/TCCA WG deliverables to update CMH-17, Vol. 3 Chapters (3, 12-14, and 17) for Rev. G
  - CMH-17 Safety Management WG initiated in 2006
  - *FAA strategy: use CMH-17 as a forum to develop guidance and document items controlled by safety management*
- **SAE CACRC (Commercial Aircraft Composite Repair Committee)**
  - ~ 75 industry engineers meet every 6-9 months (~7 WG)
  - FAA industry initiatives on maintenance/repair training show good potential for collaboration
  - CACRC Procedures TG constructed in 2008
  - *FAA strategy: use CACRC as a forum to develop guidance and support industry composite maintenance standards & training efforts (e.g., AIR 5719)*

CS&CI Building a Further Basis for AC 20-107A Updates

- **New CMH-17 Volume 3, Chapter 3 on “Aircraft Structure Certification and Compliance”**
  - Harmonized by FAA/EASA/TCCA
  - Type, Production & Airworthiness Certification relevance
  - Updates to table with Part 23, 25, 27, and 29 rules
  - Seeking industry acceptance via CMH-17 approval process
  - Links with FAA Technical Document entitled “Composite Certification Roadmap”
  - Links with FAA Technical Document entitled “Critical Technical Issues for Composite Maintenance & Repair”
- **Plans for associated CMH-17 tutorial initiated in 2007**

CS&CI Building a Further Basis for AC 20-107A Updates (cont.)

- **Updates to CMH-17 Volume 3, Chapter 12-14 on "Damage Resistance, Durability & Damage Tolerance", "Damage Types & Inspection Technology", and "Maintenance & Support"**
  - Initiated by Rotorcraft Fatigue & DT ARAC in 2002
  - Advanced by Airbus/Boeing/EASA/FAA WG Industry Workshops on Composite Damage Tolerance & Maintenance (2005-2007)
  - Links with FAA Technical Document entitled "Critical Technical Issues for Composite Maintenance & Repair"
  - Links with composite maintenance training initiative

AC 20-107B Development Plan

- FAA Established a Business Plan to Update AC 20-107A (FY 2008 & 2009)
- Key Milestones
  - ^ Document Development – (2007 – 2009)
  - ^ FAA Internal Review – Fall 2008
  - ^ Public Commenting – Spring 2009
  - ^ Final Issuance – September 2009

Post AC 20-107B Activities

AC Interaction Meetings

- Atlanta ACO Meeting (Nov/09)
- Rotorcraft Directorate Meeting (Mar/10)
- EU Industry Meeting (Hamburg, Apr/10)
- Los Angeles ACO Meeting (Jul/10)
- LA Area Industry Meeting (Jul/10)
- Denver ACO Meeting (Aug/10)
- Canada Industry Meeting (Montreal, Nov/10)
- SAD Dir. (Wichita ACO) Meeting (Mar/11)
- Chicago ACO Meeting (Aug/11)
- TAD Dir. (Seattle ACO) Meeting (Aug/11)
- Anchorage ACO Meeting (Jul/12)
- E&P Dir. (Boston & NY ACOs) Meeting (Aug/12)
- CAAs Meeting (Singapore, Sep/15)
- New Zealand Meeting & Workshop (Mar/16)

AC 20-107B Outline

AC 20-107A 11 pages
AC 20-107B 37 pages
(new sections highlighted by blue)

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*)

AC 20-107B Introductory Paragraph 1 – 5

Paragraph 1: Purpose

- Link with Parts 23, 25, 27 and 29 type certification requirements

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: Related Regulations (see Appendix 1)

Paragraph 5: General

- Provides rationale for periodic updates (evolution of composite technology, data from service experiences and expanding applications)
- Provides thoughts that the AC guidance is most appropriate for "critical structures" essential in maintaining overall flight safety of the aircraft
- Provides 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

Opening paragraph highlights need for qualified materials & processes

- Justified by effect of material & process control on composite performance

6a. Material and Process Control (new subsection)

- AC 20-107A content: Para 9f. (Production Specs) & Para 9e. (Quality Control)
- Reference to Appendix 3 (containing info on "Change of Material" taken from CS 25.603, AMC No. 1 & 2) but generalized to include Process Change
- Material requirements need to be based on qualification test results
- Environmental durability tests recommended for structural bonding
- Promotes a need to demonstrate repeatable processes at sufficient scale as related to material and process control of product structural details
- Notes 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
- Includes content on equivalency sampling tests for new users of shared data

Para. 6: Material & Fabrication Development

6b. Manufacturing Implementation (new subsection)

- Outlines need to use specifications and documentation to control materials, fabrication and assembly steps in the factory
- Importance of controlling the environment and cleanliness of manufacturing facilities to levels validated by qualification and proof of structure testing
- Need for production tolerances validated in building block tests
- Need for manufacturing records of allowed defects, rework and repair (essential for many COS-related actions)
- Expectations for accepting "new suppliers for previously certified aircraft products"

Photo courtesy of Epic Aircraft.

Para. 6: Material & Fabrication Development

6c. Structural Bonding

(new subsection ***not*** using the word secondary)

Photo courtesy of Epic Aircraft.

- Content outlining the need for qualified materials and bond surface preparation for metal bonding and composite secondary bonding
- Content on physical, chemical and mechanical qualification tests, including tests for evaluating proper adhesion (e.g., some form of peel test)
- 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.)

- 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)

- Adds words of clarification and a new sentence on a need to isolate some materials to avoid corrosion

6f. Design Values (based on AC 20-107A, 5b.)

- 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 (i.e., AC 20-107A did not recognize other composite material forms)

6g. Structural Details
(based on AC 20-107A, merging 5c. and 5d.)

- Added a sentence with thoughts on testing for the effects of impact damage

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 established acceptable path (2010 FAA policy)**
  - Conducting FAA 2010 safety awareness workshop in this area
  - Current focus on adhesives and structural bonding

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**
  - Advisory Circular (AC) 25.613-1, "Material Strength Properties and Material Design Values," dated Aug. 6, 2003
  - AC 20-107B, "Composite Aircraft Structure," dated Sept. 8, 2009
  - AC 23-20, "Acceptance Guidance on Material Procurement and Process Specifications for Polymer Matrix Composite Systems," dated Sept. 19, 2003
  - AC 27-1, "Certification of Normal Category Rotorcraft", dated Sept. 30, 2008
  - AC 29-2, "Certification of Transport Category Rotorcraft", dated Sept. 30, 2008
  - PS-ACE 100-2002-006, "Material Qualification and Equivalency for Polymer Matrix Composite Material systems," dated Sept. 15, 2003
- **Reference Material**
  - DOT/FAA/AR-03/19, "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure," dated September 2003 Link - http://www.tc.faa.gov/its/worldpac/techrpt/ar03-19.pdf
  - NCAMP Standard Operation Procedures (SOP), Doc. # NSP 100 (E), dated December 22, 2009

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*)

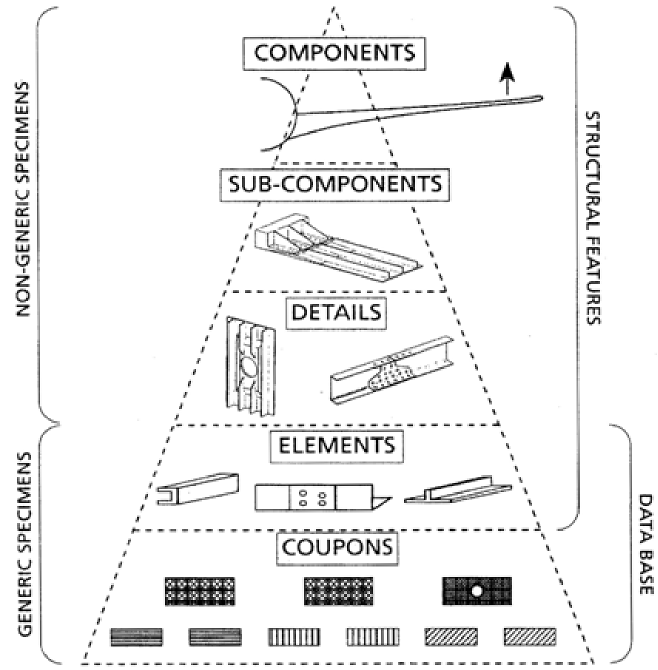


Figure A. Schematic diagram of building block tests for a fixed wing.

Definition of Structural Bonding

Differences between

Lamination of uncured resins and adhesives

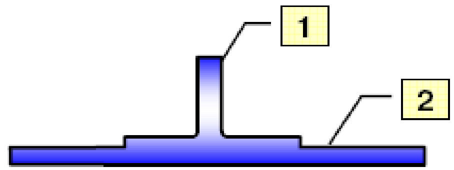
and

Structural Bonding (i.e., Secondary Bonding) when surface preparation is a critical process step

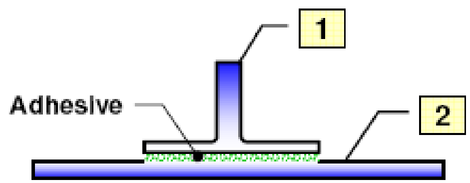
AC 20-107B

Structural Bonding: A structural joint created by the process of adhesive bonding, comprising of one or more previously-cured composite or metal parts (referred to as adherends)

Bonded Assembly / Interfaces



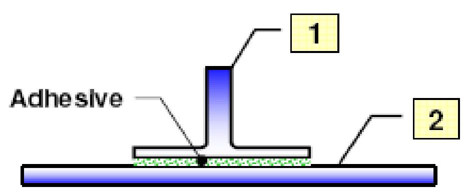
CO-CURING: Components cured together
- Component 1 un-cured
- Component 2 un-cured



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

AIRBUS

Taken from FAA Workshop (6/09, Japan)

Technical Scope of the 2004 Bonded Structures Workshops

Material & Process Qualification and Control

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

Manufacturing Implementation and Experience

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, propellers and transport aircraft

Design Development and Structural Substantiation

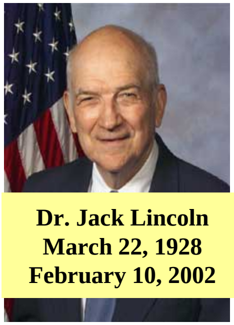
Commercial and military applications were reviewed

Repair 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



Dr. Jack Lincoln
March 22, 1928
February 10, 2002

THE TECHNICAL CO-OPERATION PROGRAM

TTCP

SUBCOMMITTEE ON NON-ATOMIC MILITARY RESEARCH AND DEVELOPMENT

CERTIFICATION OF BONDED STRUCTURES

Prepared by

ACTION GROUP 13
OF
THE TECHNICAL COOPERATION PROGRAM

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

•Success story
•of DOD/FAA/Industry
•collaboration

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

U.S. Department of Transportation
Federal Aviation Administration

Subject: **INFORMATION**: Bonded Joints and Structures - Technical Issues and Certification Considerations; PS-ACE100-2005-10038

Date: **DRAFT**

From: Acting Manager, Small Airplane Directorate, ACE-100

Reply to Attn. of: Lester Cheng; 316-946-4111

To: See Distribution

- **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.

Para. 7: Proof of Structure - Static

AC 20-107 B content increased from 1 to 3.5 pages

Eliminated AC 20-107A 6f.

Opening statement

- 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

- Adds a reference to effects of environment on material properties (6d.) and protection of structure (6e.)
- Two approaches to account for repeated load and environment: (same as fifth area of AC 29-2C, MG8)
    1) Test demonstration following exposure
    2) Account for known degradation with overload factors

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

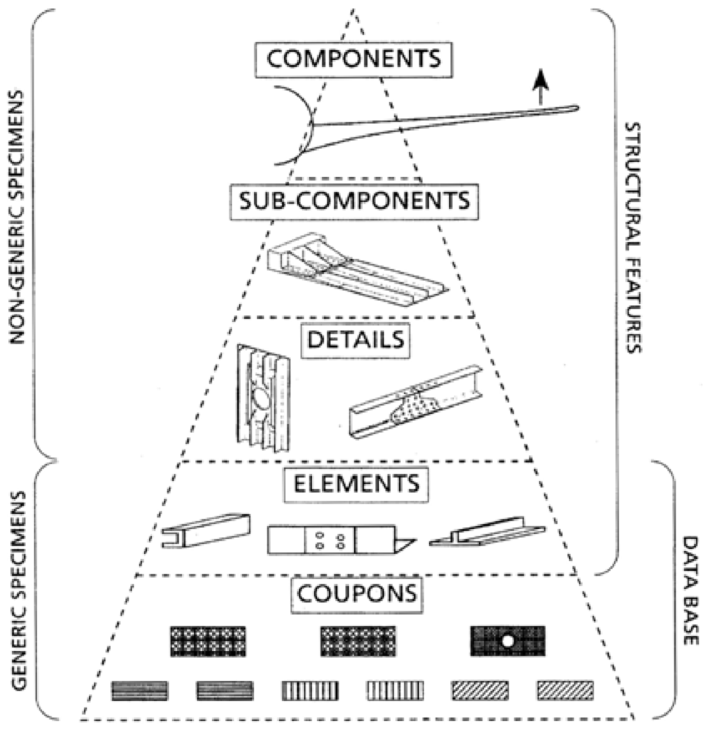


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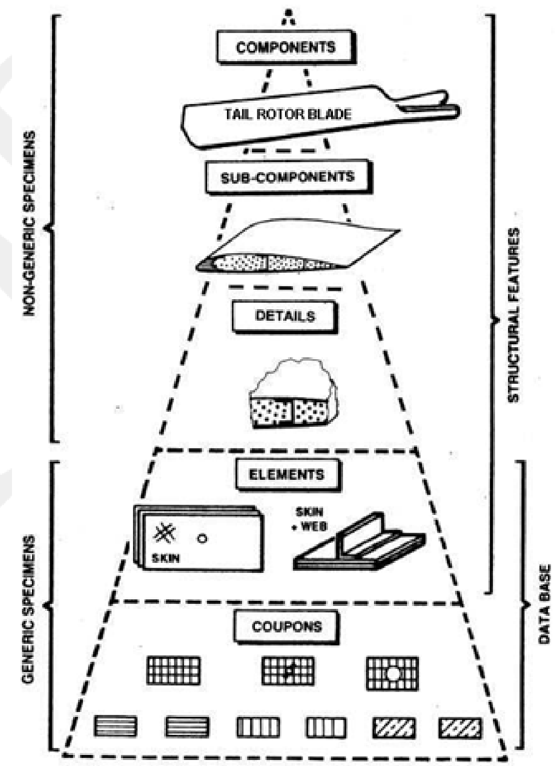
Figure A. Schematic diagram of building block tests for a fixed wing.



¶
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.)

- Somewhat 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 substantiated manufacturing acceptance criteria

7e. Material & process variability considerations (based on AC 20-107A, 6e.)

- 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)*

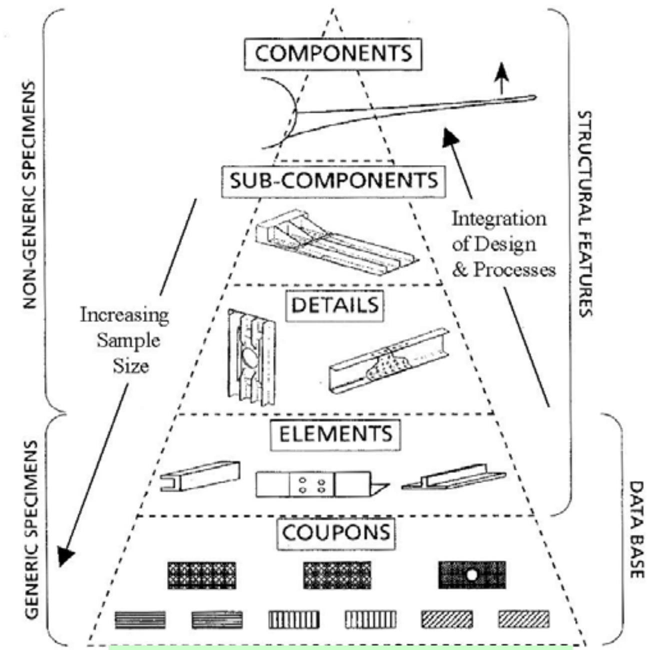
7f. Non-detectable impact damage (based on AC 20-107A, 6g.)

- 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**



Building Block Tests & Analysis

Past Part 23 TC Projects with Extensive Use of Composites in Airframe Structure

Raytheon Premier I

Used "*an analysis supported by test approach*" to avoid overload factors for variability

Cirrus Design Corp. SR20

PAC USA Lancair LC40-550FG

Comments & suggestions associated to § 5 (Cont'd 4) of AC 20-107A

•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 this sub-paragraph was followed for AC 20-107B.

•*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**

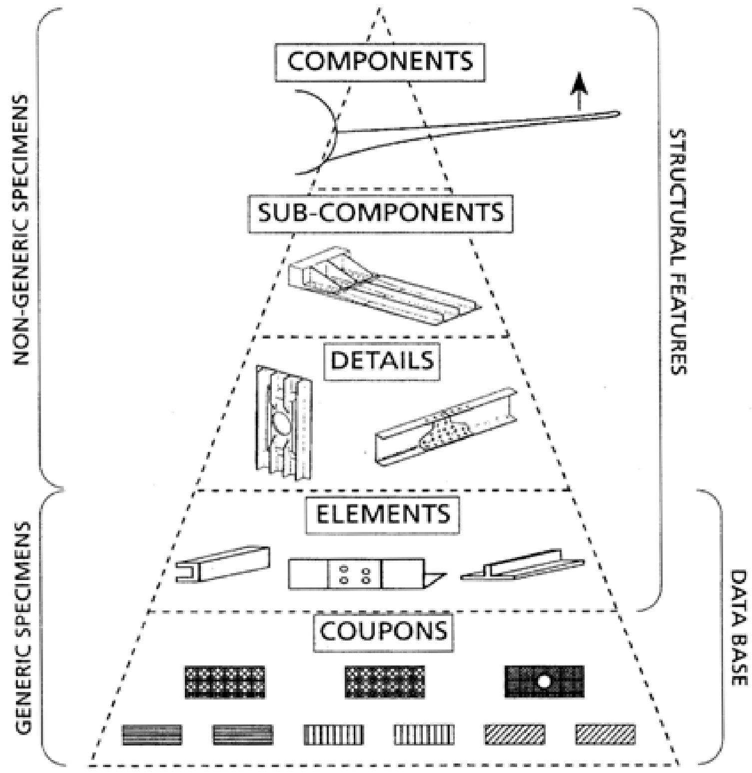


Figure A. Schematic diagram of building block tests for a fixed wing.

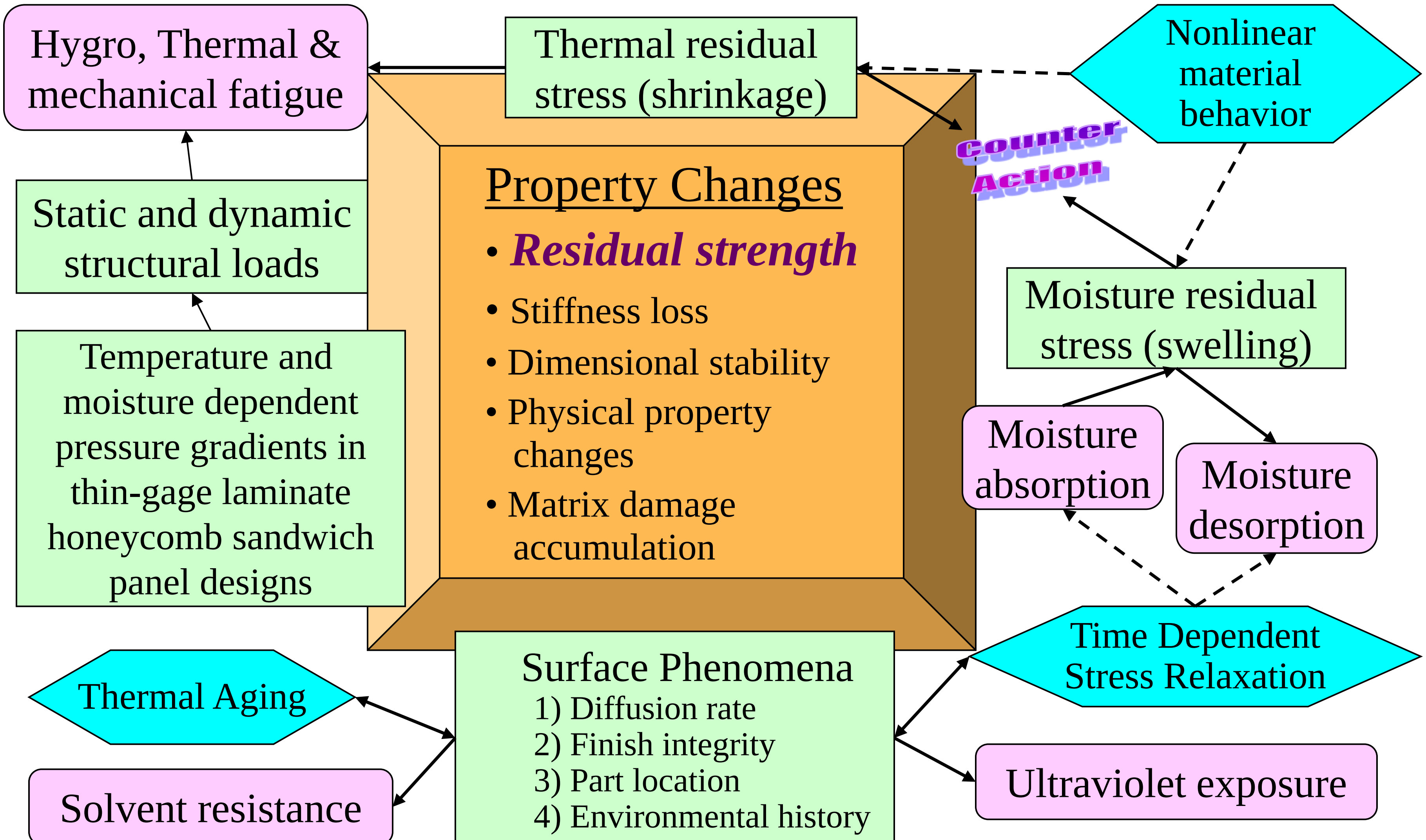
Proof of Structure - Static

- **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



Covered in more detail by EnvRLoad.ppt SSS Workshop

Composite Structure Service Experience

Good Service History

NASA—ACEE/Boeing 737 Horizontal Stabilizer Certified in 1982

Most composite secondary parts & control surfaces since 1980s have had no problems

All composite horizontal stabilizer and vertical fin main torque box structures on A300, A310, A320, A330, A340 and B777 aircraft since the 1980/1990s have had no problems

FAA/NASA/Boeing Research
Tear-down inspection of 737 composite horizontal stabilizers to evaluate aging and long-term performance found no problems

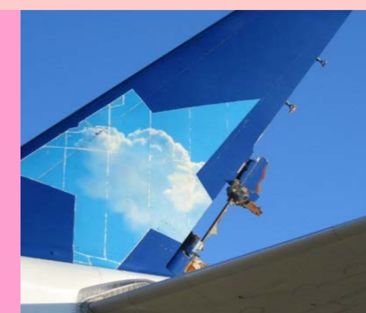
1970s	1980s	1990s	2000s	2010s

Composite Lessons Learned

Some composite secondary parts & control surfaces since 1980s have economic problems
- Environmental durability (kevlar/epoxy parts removed)
- Fragile/poor design details
- Non-standard repair is an economic problem for airlines

Some composite primary control surfaces since the 1980s have both safety and economic problems
- Disbond growth from poor repair, design & mfg. details
- Expensive inspection and repair or replacement an economic burden for airlines

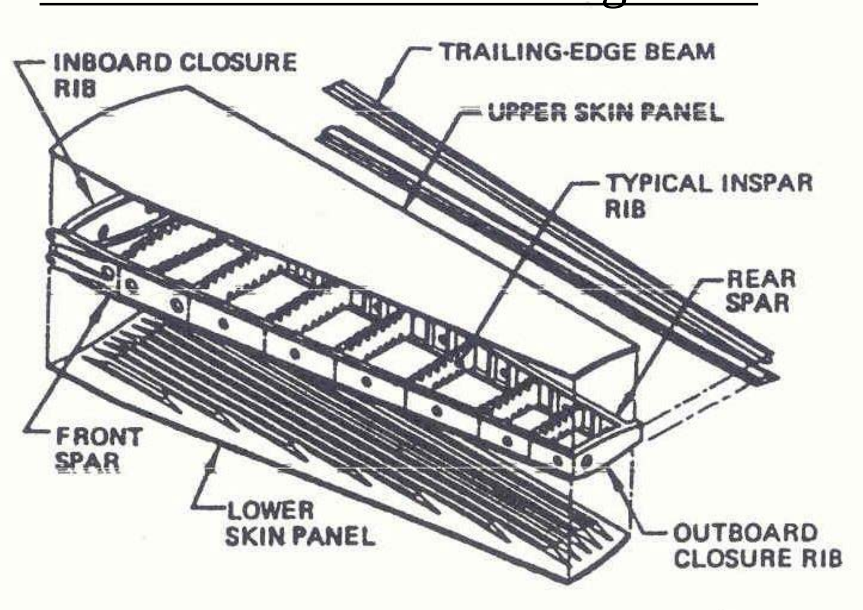
Air Transat Flight 961



Service Experiences for Boeing 737 Composite Horizontal Stabilizer

Developed and certified under NASA Aircraft Energy Efficiency, ACEE, program (1977-1982)

NASA ACEE 737 Horizontal Stabilizer Structural Arrangement



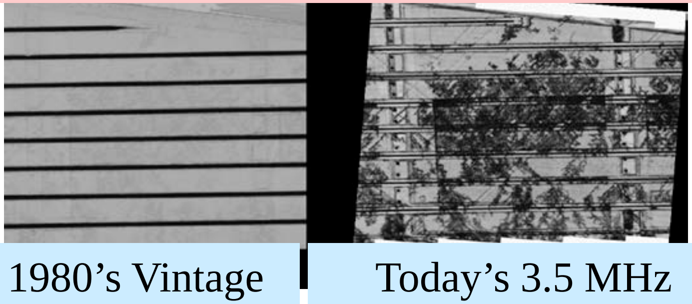
- **Five shipsets entered service in 1984**
- **Structural inspection program that included detailed visual inspection, with some pulse-echo ultrasound in specific areas to collect fleet data**
- **Four significant service-induced damage events to main torque box structure as of 2001 technical paper:**
  - (1+2) De-icer impact damage to upper surface skins
  - (3) Fan blade penetration of lower surface skin
  - (4) Severe impact damage to front spar web and upper & lower chord radii

Taken from: "Composite Empennage Primary Structure Service Experience," G. Mabson, A. Fawcett and G. Oakes, CANCOM Conference, Montreal, Canada, August 2001.

B737 Horizontal Stabilizer Teardown Inspection

- **Inspections found little deterioration due to wear, fatigue, or environmental factors**
- **Production NDI results indicated that today's factory "standard" is advanced beyond that of early 1980s**
  - High levels of porosity are evident in much of the composite structure
- **Mechanical tests of coupons and elements cut from B737 stabilizers had residual strength equivalent to those obtained more than 20 years ago**

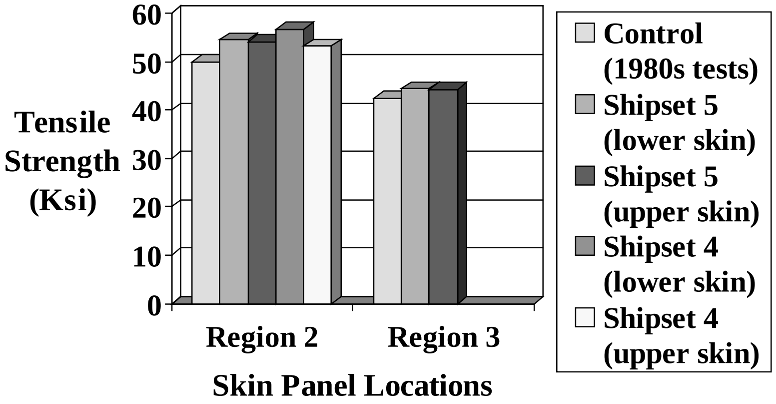
Factory Ultrasonic Scans of Skin Panels



1980's Vintage 1 MHz ATTU

Today's 3.5 MHz Thin Film Pulse Echo

Residual Strength After Service

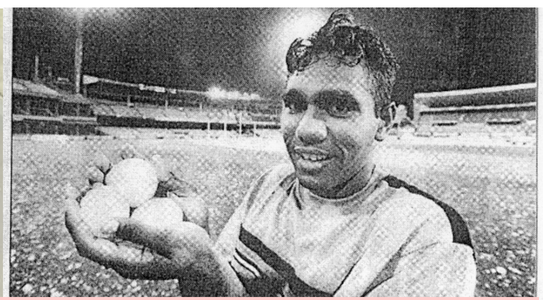


Taken from: "Structural Teardown Inspection of an Advanced Composite Stabilizer for Boeing 737 Aircraft," D. Hoffman, J. Kollgaard and Matthew Miller, 8th Joint FAA/DoD/NASA Aging Aircraft Conference, January, 2005.

History of Composite Service Problems

- **Composites used in fragile, thin-gaged control surfaces and secondary structures pose some problems for airlines**
  - Prone to damage from impact and environmental exposures (has not proved to be a safety issue, instead it has been an economic burden)
  - In many cases, the problems can be traced to bad design details
- **Lack of industry standardization and training for maintenance**

Dents and Punctures on Boeing 757 Inboard Aft Flap (thin skin of composite sandwich)

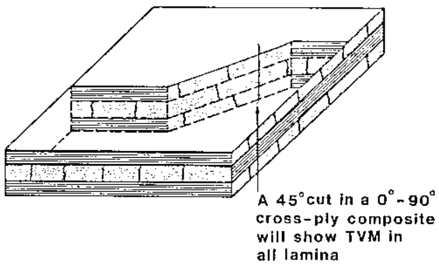


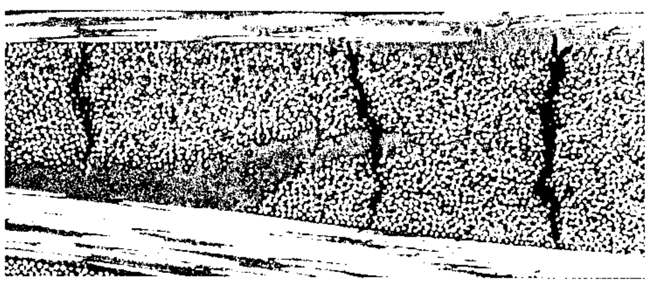
Example of Hail Damage from 1999 Sydney Storm

Dents on Boeing 777 Aft Flap (thin skin metal bonded sandwich)

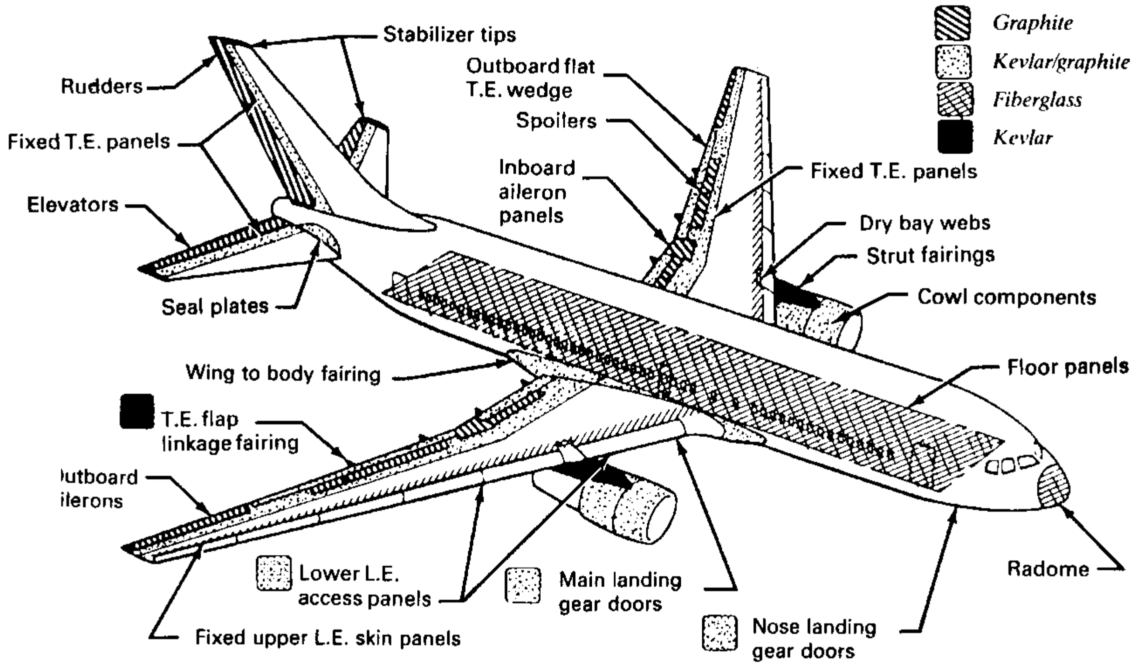
Environmental Durability Problems from Early Use of Aramid/Epoxy Materials

Transverse Matrix Cracking (TVM) of aramid/epoxy sandwich facesheets yielded a path for water ingression into honeycomb core





ELECTRON MICROGRAPH OF TVM IN FABRIC



Boeing 767 Aircraft Developed in 1980s

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

Content increased from 1 to 8 pages

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

Opening paragraph

- 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)

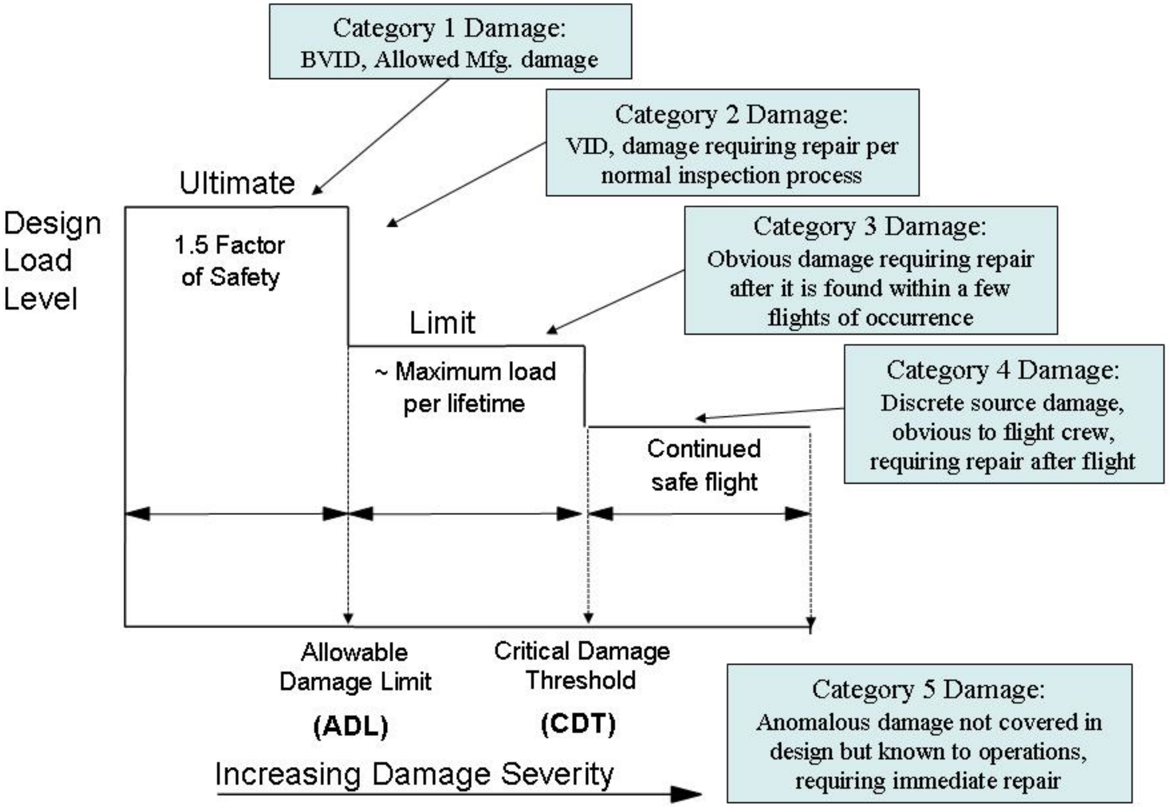
- Add text on identification of critical elements and a need for damage threat assessment (words taken from the new rule, 14 CFR 29.573)
- Described considerations for damage threat assessment of a given structure

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))

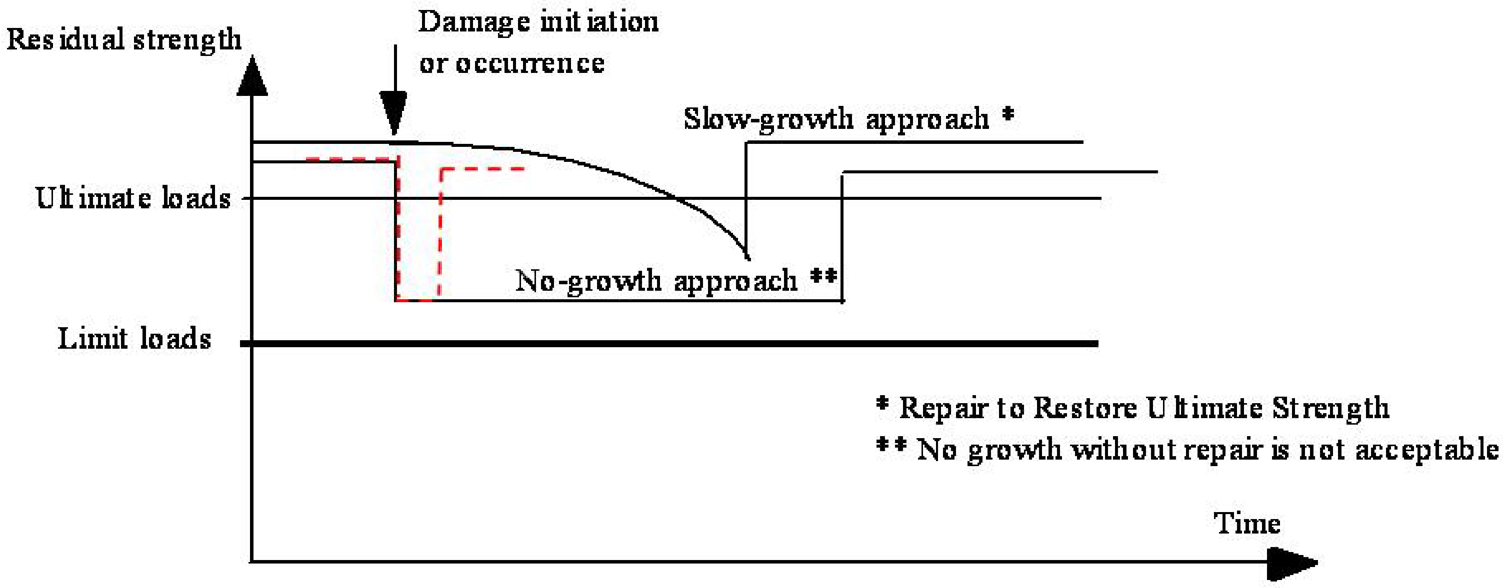
- Keeps all text from AC 20-107A, 7a (1)
- Adds AC 29-2C, MG8 text on inspection intervals for a no growth approach, established considering residual strength of assumed damage.
- Adds AC 29-2C, MG8 text on slow growth and arrested growth options, including conditions when they are allowed (stable and 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)



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

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

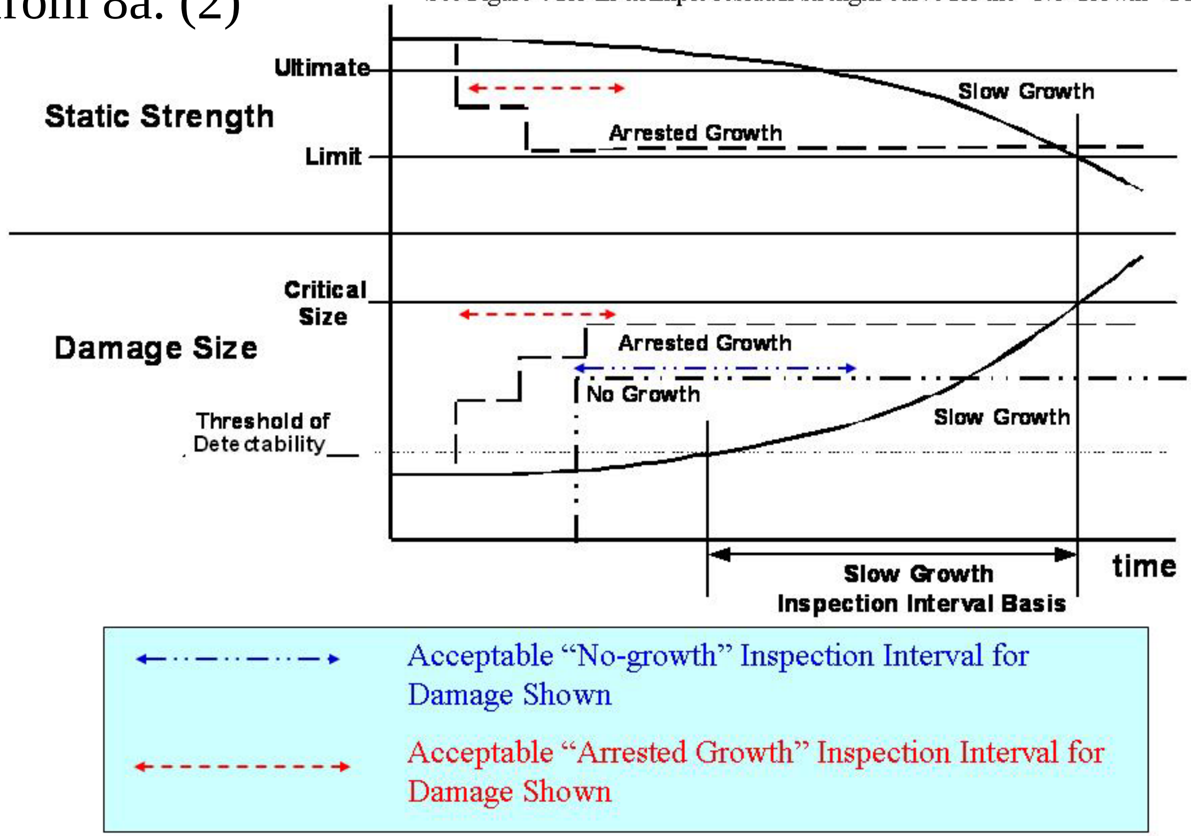
Para. 8: Proof of Structure – Fatigue/Damage Tolerance

8a. Damage Tolerance Evaluation

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

– Figures from 8a. (2)

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



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))

- 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))

- 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)
- Notes 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))

- Adds text to refer back to Figures 4 & 5 for unacceptable time intervals in detecting larger no-growth and arrested growth damage sizes
- Discusses different inspection intervals for category 2 & 3 damage types
- Need for expanded conditional 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 sentence linking Category 1 damage to this evaluation, incl. 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 service life limits (similar to metals)
- Expectations for increasing structural life of composite parts
  1) Evidence from component repeated load testing
  2) Fleet leader programs (incl. NDI and destructive tear-down inspections)
  3) 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

	Wednesday, July 19	Thursday, July 20	Friday, July 21
1st Hour	CMH-17 COMPOSITE MATERIALS HANDBOOK	Session 2* **Substantiation of Structural Damage Tolerance**	Session 6 **Technical Breakout Sessions** (*Separate *working meetings covering technical subjects from Sessions 2 - 5*)
2nd Hour			
Break (15 min.)			
3rd Hour		Session 3* **Structural Test Protocol**	Session 7 **Breakout Team Summary** Recap/Actions/Closure/Adjourn
4th Hour			
Lunch (1 Hour)			
5th Hour	**FAA Initiatives Safety Management** Airbus/Boeing/EASA/FAA WG Maintenance Training Update	Session 4* **Substantiation of Maintenance Inspection & Repair Methods**	
6th Hour			
Break (15 min.)			
7th Hour	Session 1 **Applications & Service Experiences**	Session 5* **Damage/Defect Types and Inspection Technology**	
8th Hour			

Chicago, IL, USA
July 19-21, 2006

~150 Participants

2007 FAA/EASA/Industry Composite Damage Tolerance and Maintenance Workshop

Amsterdam, Netherlands May 9-11, 2007

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

~110 Participants

2009 FAA/EASA/Industry Composite Damage Tolerance and Maintenance Workshop

Tokyo, Japan June 4 & 5, 2009

	Thursday, June 4	Friday, June 5
1st Hour	**FAA Initiatives** Recent Progress/Safety Management	**Session 4*** **Damage Tolerance & Maintenance Guidance** Near- and Long-term Needs Design and Process Guidance Structural Substantiation = f(application criticality)
2nd Hour	**EASA Initiatives** **Session 1: Applications & Field Experiences**	
Break (15 min.)		
3rd Hour	**Session 1: Applications & Field Experiences** *(continued)* Service History of Critical Composite Structure Service Damage & Reliability of Repairs (all applications) Anticipated issues for expanding applications	**Session 5*** **CACRC Advances for the Future** Near and Long-term Initiatives Shared Databases and Methods Design & Process Guidelines = f(application criticality)
4th Hour		
Lunch (1 Hour)		
5th Hour	**Session 2*** **Damage Threats & Inspection Strategies** Data for Damage Threat Assessments Test Standards & Inspector Qualifications Reliable Technology Advances for Inspection	**Session 6** **Technical Breakout Sessions** (*Separate *working meetings covering technical subjects from Sessions 2 - 5)*
6th Hour		
Break (15 min.)		
7th Hour	**Session 3*** **Damage Tolerance & Repair Substantiation** Design Criteria & Objectives Building Block Approaches (benefits & est. costs) Structural Test & Analysis Protocol	**Session 7** **Breakout Team Summary** **Recap/Actions/Closure/Adjourn**
8th Hour		

~120 Participants

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/

Top-Level Agenda for 2011 FAA/EASA/Industry Composite Transport

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

Top-Level Agenda for 2015 FAA/EASA/Industry Composite Transport

Top-Level Draft Agenda for 2015 FAA/Bombardier/TCCA/EASA/Industry Composite Transport Damage Tolerance and Maintenance Workshop (Montreal, Quebec)

Revision 4

	Tuesday, September 15	Wednesday, September 16	Thursday, September 17
1st Hour / 2nd Hour	*Bombardier Welcome* & **Workshop Intro** **FAA/EASA/TCCA Composite** **Damage Tolerance & Maintenance Initiatives** Background/Plans/Workshop Objectives Overview of Relevant Technical Issues	**Session 3: High Energy, Wide Area, Blunt Impact (HEWABI)** Industry Experiences and Regulatory Interface FAA/EASA/Industry research *(eval. supporting tech.)* **Recap (30 min):** Review Industry Experiences and Safety Risk Mitigation Efforts	**Session 6** **Damage Tolerance: Part 2B** (Special Subjects) Hybrid issues for composite & metal assemblies Thermal loads (analysis and sufficient test evidence) Flights with known damage (substantiation) Substantiation of maintenance inspection technologies
Break (15 min.)			
3rd Hour	**Session 1: Sandwich Disbond Assessment/Recap** Standards and Structural Engineering Methods	**Session 4A** **Composite Fatigue and Damage Tolerance** Aging aircraft (limits of validity, other constraints) Design Criteria & Objectives for Category 2 -4 Large Scale Structural Analysis & Test Protocol	**Damage Tolerance Recap** Review Industry Experiences & Substantiation Efforts for Fatigue & Damage Tolerance (support Sessions 6)
4th Hour	**Session 2A (part 1): Bonded Repair** Field Experiences Operator Perspectives on Bonded Repairs		**Session 7a: Smarter DT Testing** Transport "Advanced Analysis" Evaluation Novel Building Block Methods
Lunch (45 min.)	Lunch	Lunch	Lunch
5th Hour	**Session 2A (part 2): Bonded Repair** Field Experiences OEM Perspectives on Bonded Repairs	**Session 4B** **Composite Fatigue and Damage Tolerance** Repeated Load Tolerance (fatigue & damage tolerance) Design Requirements & Criteria Ongoing Part 25 Fatigue & DT ARAC Efforts	**Session 7b: Use of Probabilisitc Methods** Damage Threat Assessments *(field data)* Combined Structural/Maintenance Safety Analysis
6th Hour	**Session 2B (part 1): Bonded Repair** Round Robin Test Results/Training Pros and Cons Factors Affecting Bond Quality		**Session 7C: Major Structural Modifications, Alterations & Repairs** Review Industry Experiences & Substantiation Efforts
Break (15 min.)			
7th Hour	**Session 2B (part 2): Bonded Repair** Competency for Specific Product Details Bonded Repair Substantiation, Standards	**Session 5** **Damage Tolerance: Part 2A** (Special Subjects) Building Blocks for Analysis Supported by Tests	**Near-term Emerging Technology Recap** Review Experiences & Substantiation Efforts for Promising Emerging Technologies (support Sessions 7A, 7B, & 7C)
8th Hour	**Bonded Repair Recap** Review Industry Efforts: CMH-17 Working Groups Best Practices/Case Studies (support Sessions 1 & 2)	**Fatigue and Damage Tolerance Recap** Review Industry Experiences & Substantiation Efforts for Fatigue & Damage Tolerance (support Sessions 4A, 4B & 5)	**Workshop Recap and Closure**

The above agenda provides a current view of the workshop at a high level. See the detailed agenda for more a specific time allocation within each session.

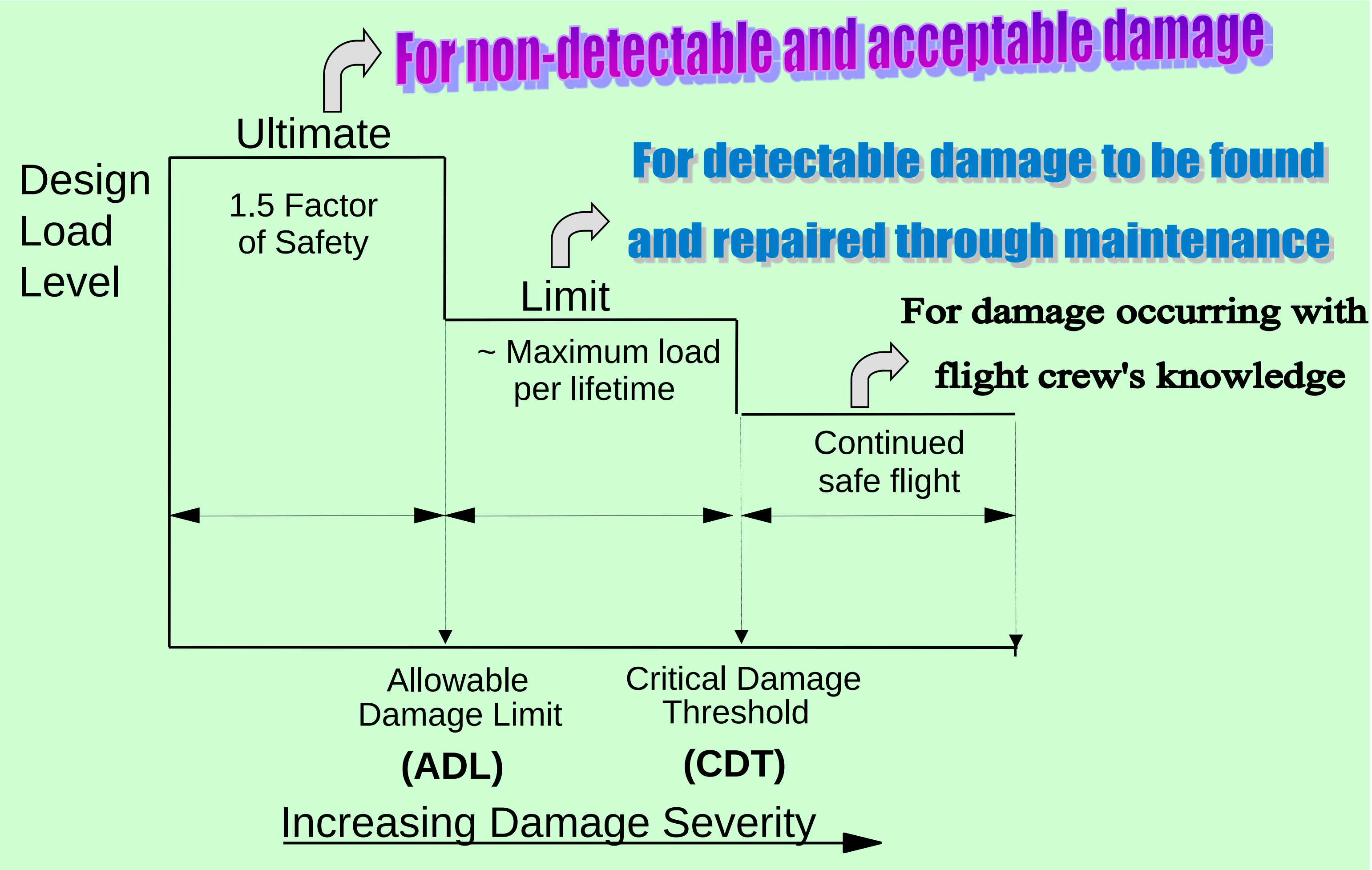
Notes: *1) The last hour of the first 2 days are recap sessions. Participants may leave once they have completed comment forms and have no need to be part of discussions.*
2) The third day will end 30 to 45 minutes early.

Damage Threat Assessment for Composite Structure

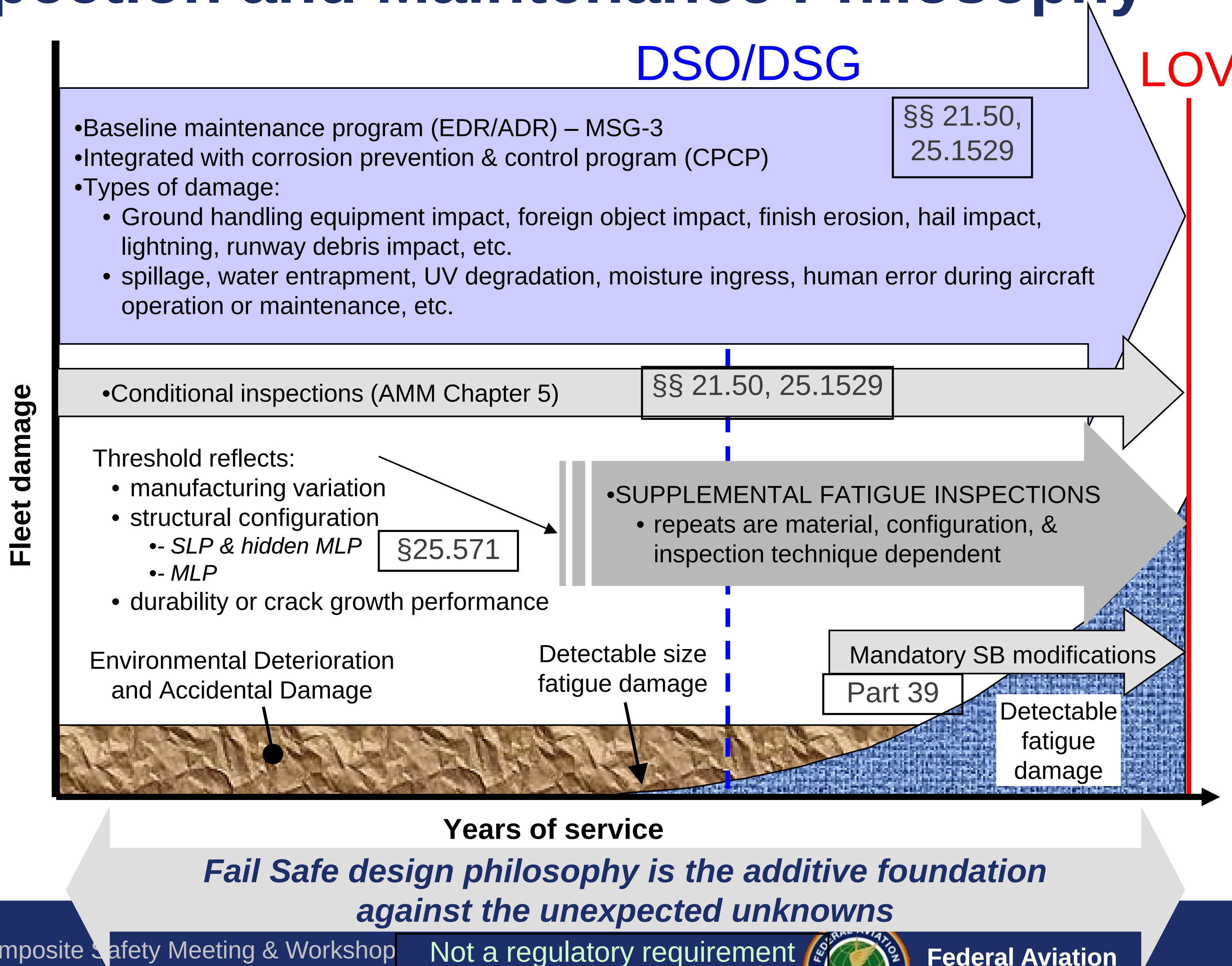
FAR 25.571 Damage Tolerance & Fatigue Evaluation of Structure … must show that catastrophic failure due to fatigue, corrosion, *manufacturing defects, or accidental damage* will be avoided through the operational life of the airplane.

AC 20-107A Composite Airplane Structure: 7. <u>Proof of Structure – Fatigue/Damage Tolerance</u> (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



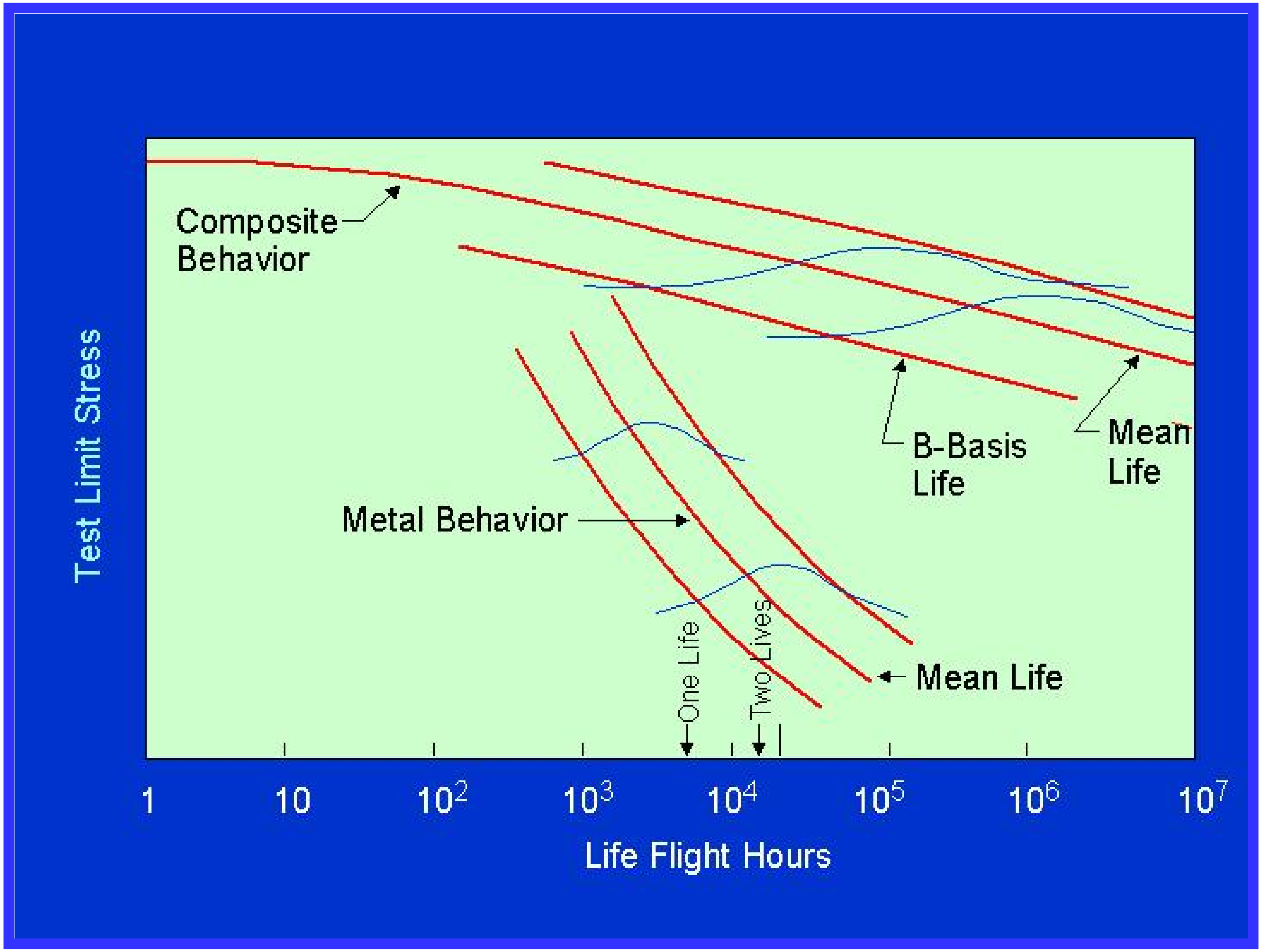
Inspection and Maintenance Philosophy



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



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.

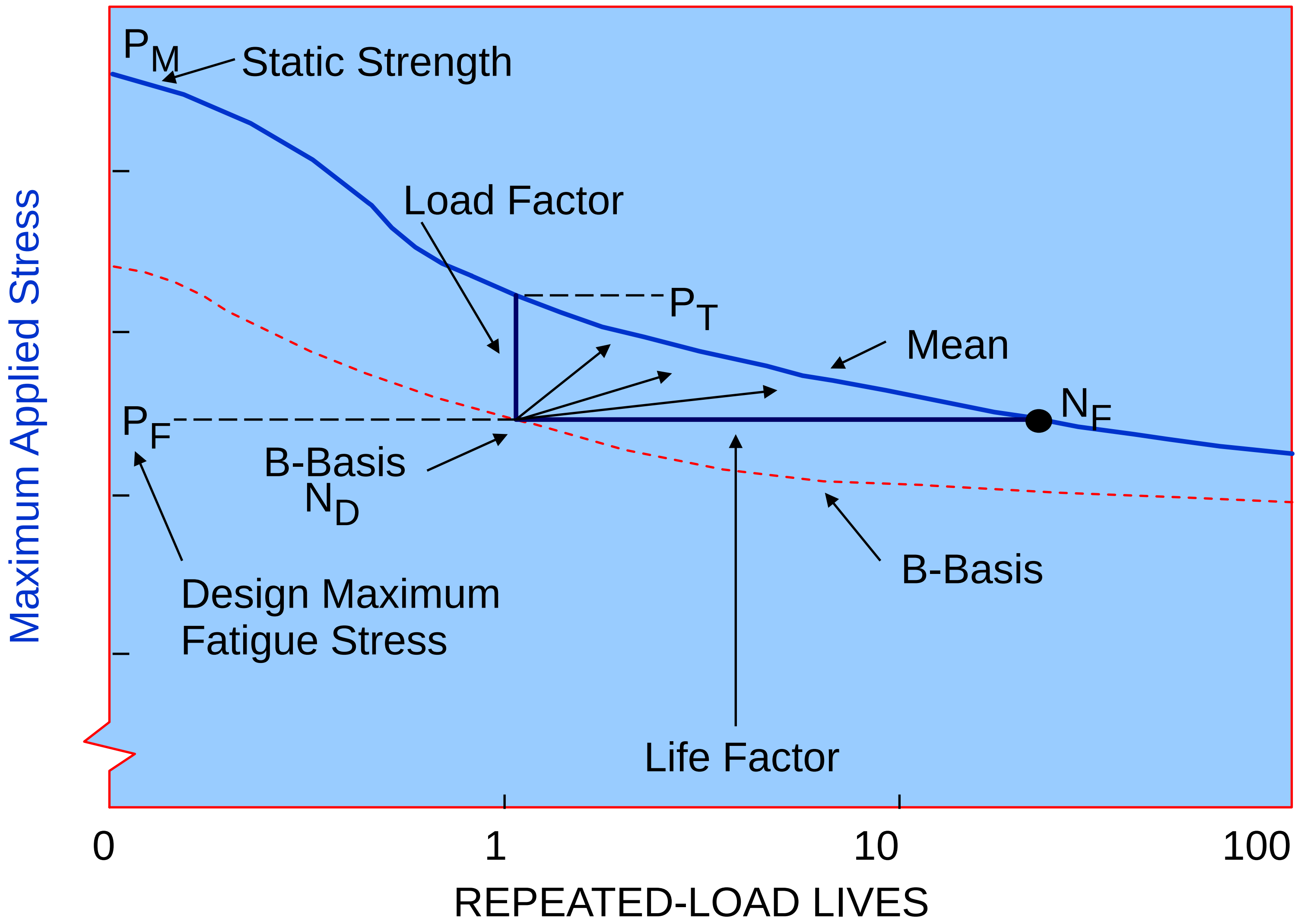
- **Manufacturing defects and impacts**
  - Evaluate complex damage that triggers interactions between interlaminar and translaminar failure modes for *anomalous fatigue* *(i.e., damage tolerance demonstration)*
  - Compression & shear strength affected by damage
  - Similar tensile residual strength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

Cycles for Fatigue Testing

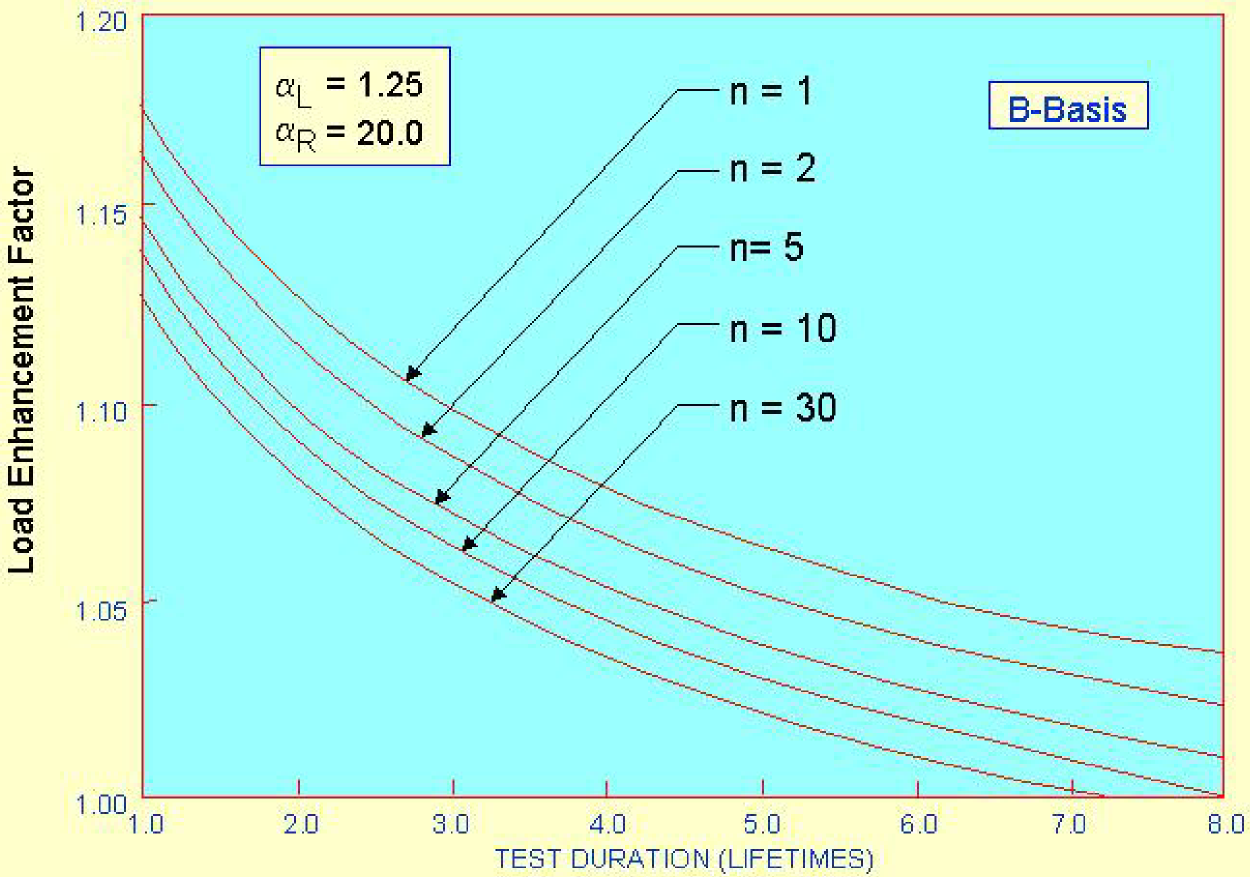
"... Should be statistically significant, and may be determined by load and/or life considerations"
AC 20-107A, Composite Aircraft Structure, Sec. 7(a)(2)

- 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



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

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

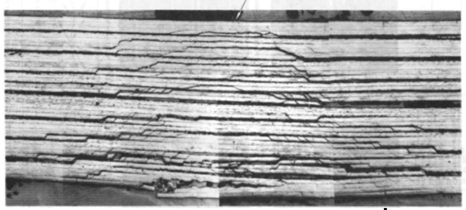
Category	Examples (not inclusive of all damage types)
Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)	Barely visible impact damage (BVID), scratches, gouges, minor environmental damage, and allowable mfg. defects that retain ultimate load for life
Category 2: Damage detected by scheduled or directed field inspection @ specified intervals (repair scenario)	VID (ranging small to large), deep gouges, mfg. defects/mistakes, major *local* heat or environmental degradation that retain limit load until found
Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)	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
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)	Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning, exploding gear tires, severe in-flight hail)
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	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

Categories of Damage

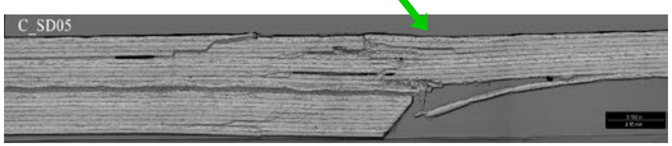
Category 1: *Allowable damage that may go undetected by scheduled or directed field inspection*
(or allowable manufacturing defects)

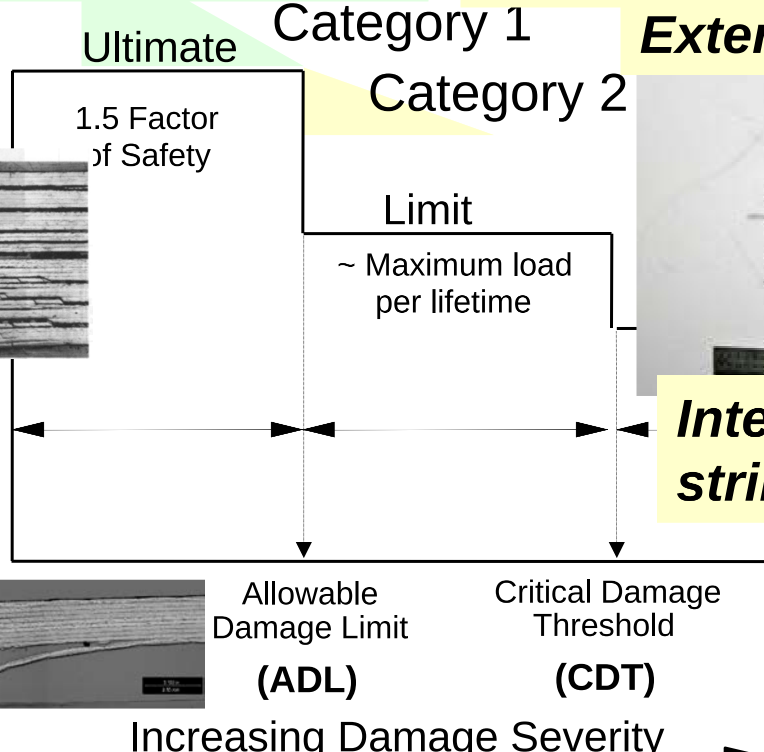
Category 2: *Damage detected by scheduled or directed field inspection at specified intervals*
(repair scenario)

X-sec of BVID at Skin Impact Site



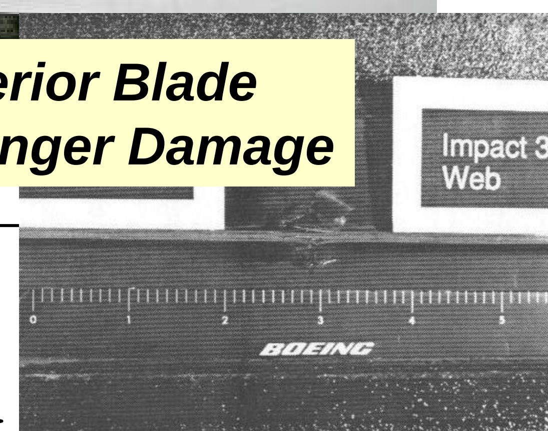
X-sec of BVID Impact at Flange to Skin Transition





Exterior Skin Damage

Interior Blade stringer Damage

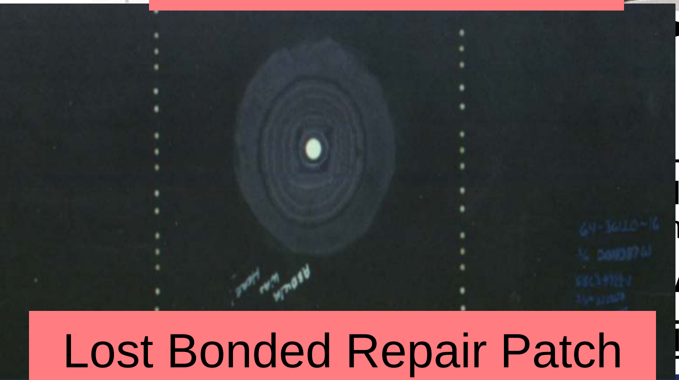


Categories of Damage

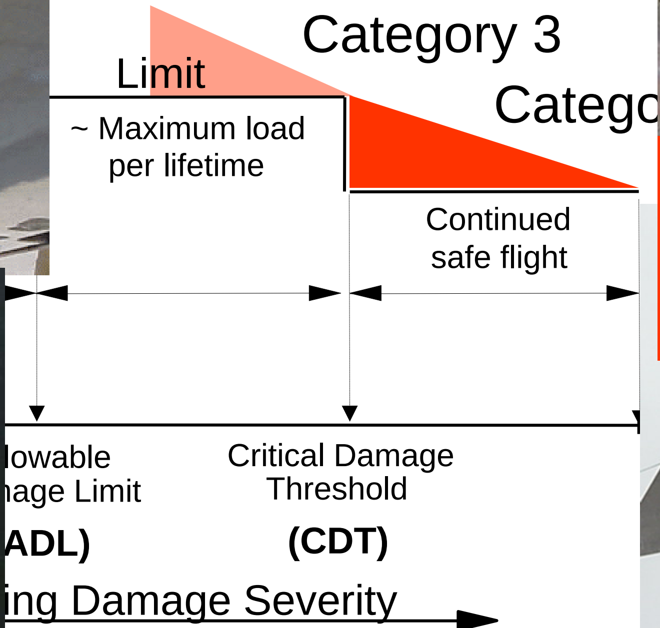
Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)

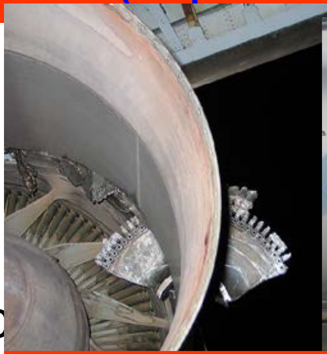
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)

Accidental Damage to Lower Fuselage

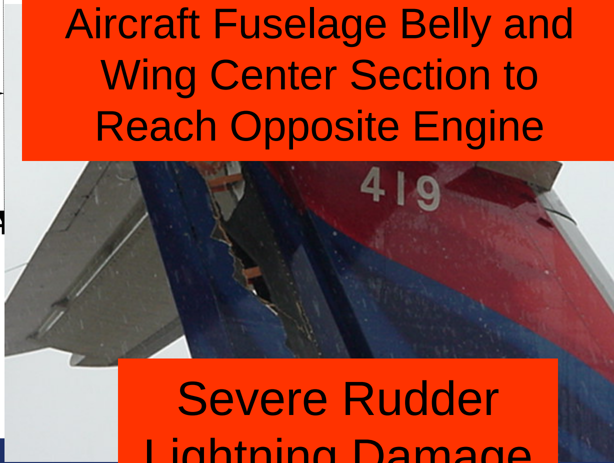


Lost Bonded Repair Patch





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



Severe Rudder Lightning Damage

Categories of Damage

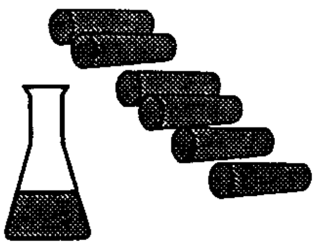
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)

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

Material variables



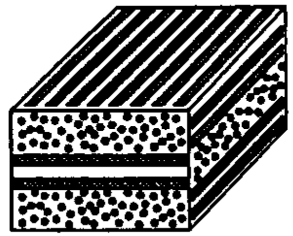
☆ Fiber
- AS4
- IM7

☆ Resin
- 938 (3501-6)
- 977-2

☆ Fiber volume
- 0.480
- 0.565

☆ Material form
- Tape
- Tow

Laminate variables

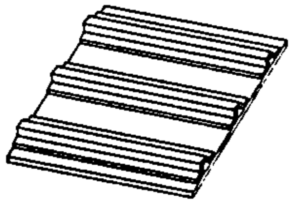


Stiffener layup
- Hard
- Soft

Skin layup
- Hard
- Soft

☆ Thickness
- Thick (approximately 0.2 in)
- Thin (approximately 0.1 in)

Structural variables

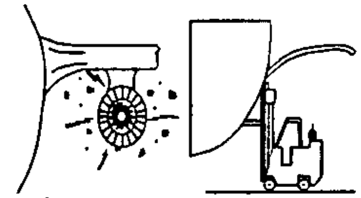


☆ Stiffener type
- Blade
- Hat

Stiffener spacing
- 7 in
- 12 in

☆ Stiffener adhesive layer
- With
- Without

Extrinsic variables



Impact mass
- 0.5 lbm
- 12.0 lbm

☆ Impact energy (skin/stiffener)
- 80 in-lb/200 in-lb
- 1,200 in-lb/2,000 in-lb

Impact temperature
- 70°F
- 180°F

☆ Impact diameter
- 0.25 in
- 1.0 in

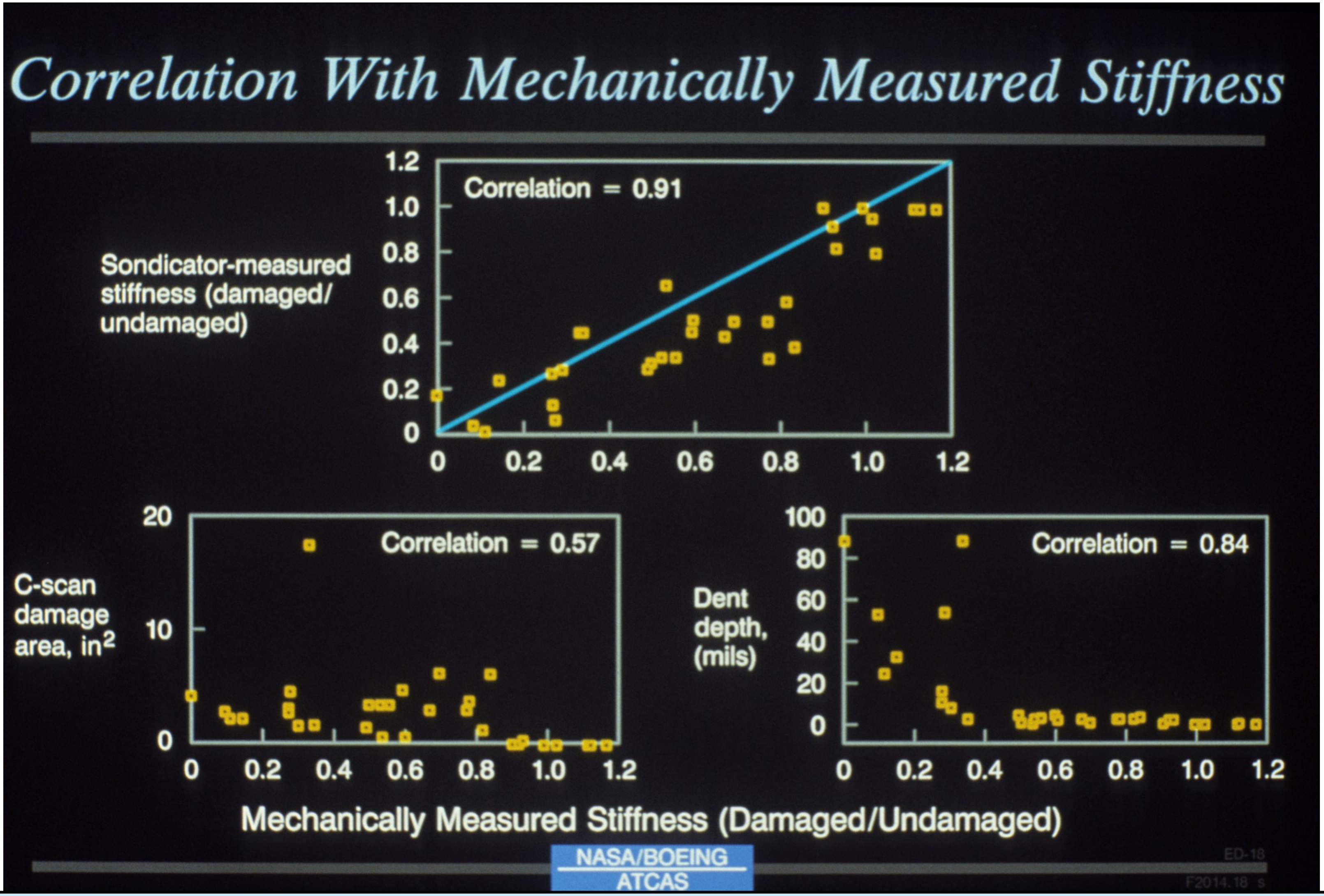
☆ Impactor tup shape
- Flat
- Spherical

Impactor stiffeness
- 0.5 Msi
- 30 Msi

☆ 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.

"Impact Damage Resistance of Composite Fuselage Structure," E. Dost, et al, NASA CR-4658, 1996.

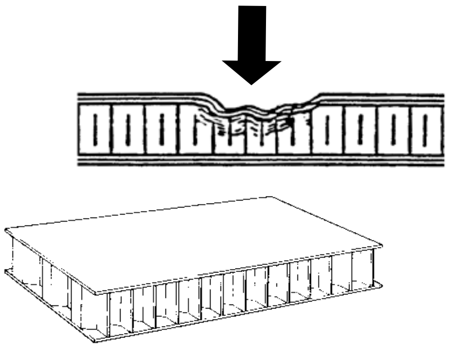
Impact Design Experiment Results

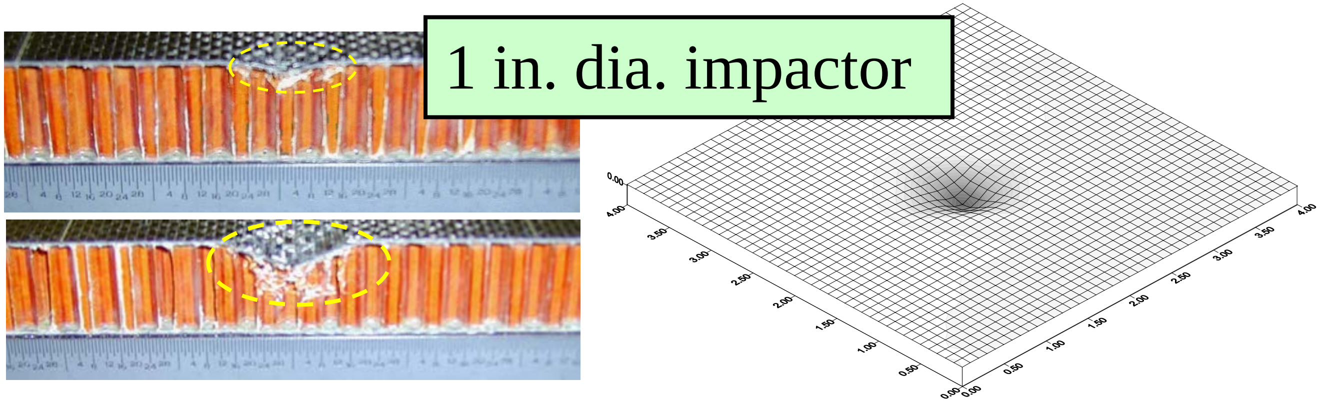


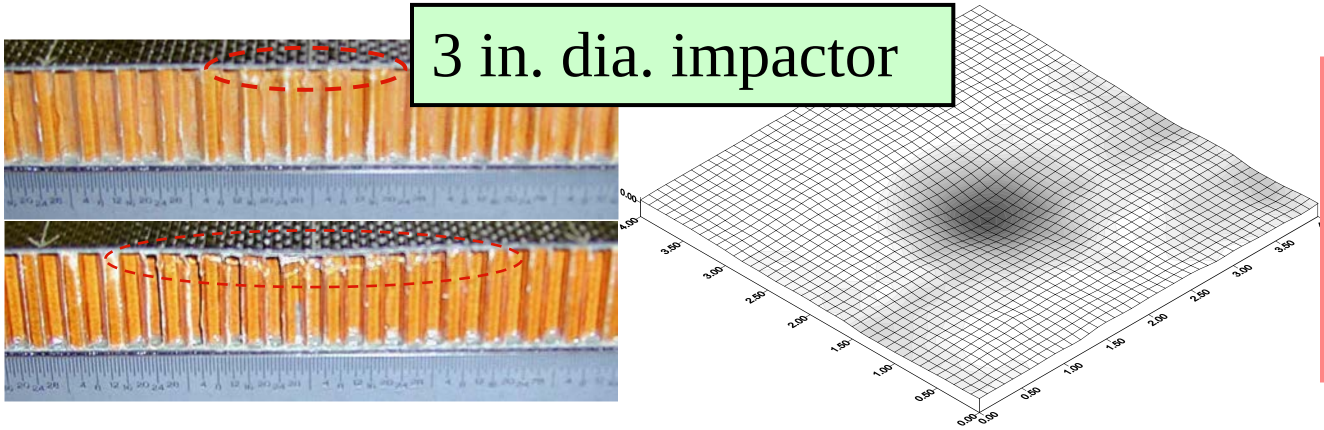
"Impact Damage Resistance of Composite Fuselage Structure," E. Dost, et al, NASA CR-4658, 1996.

Factors Affecting Placement of Damage Threats in Categories

Foreign-Object Impact is Complex



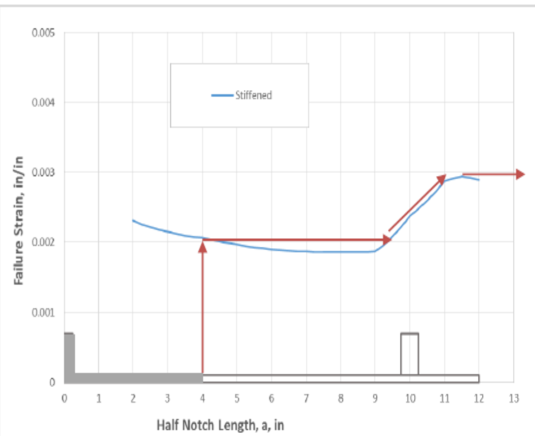


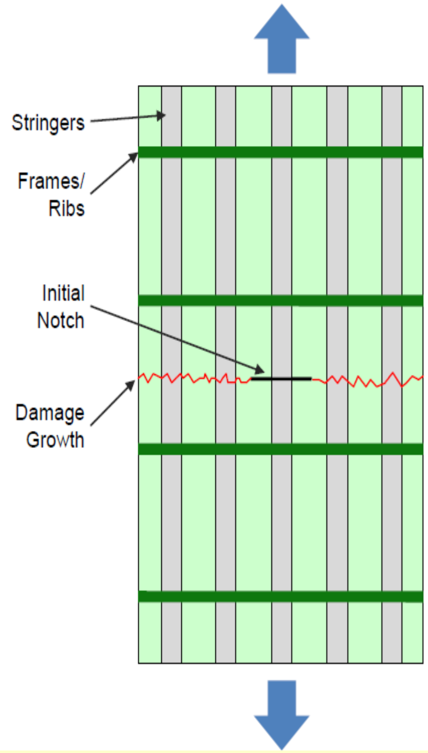


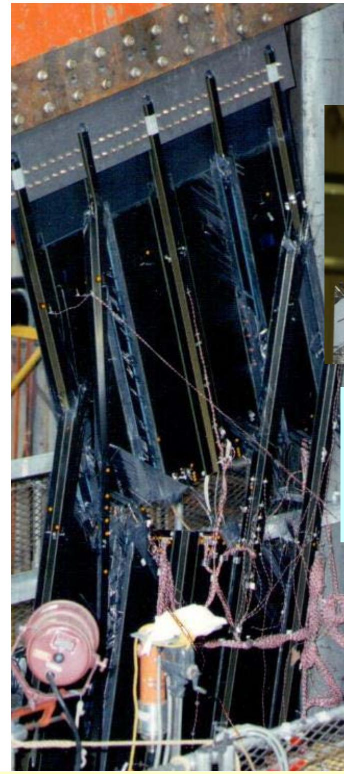
Some NDI may be needed to place damage at the left into Category 2

Large Damage Capability/ Residual Strength Curve Shape

- General response for uniaxial loading of a notch severing a central stiffener
  - Damage growth in the skin
  - Arrest at intact stiffener
  - Failure of stiffener and/or skin/stiffener attachment
  - Unstable damage growth in the skin







- Notch damage details
- For a large notch tensile
- residual strength test

•The uncertainties of impactor variables versus the visual detectability of relatively small impact threats like Category 1 (e.g., BVID) and small Category 2 damage can effectively be balanced by “large damage capability” such as Category 3 damage.

Tom Walker, CMH-17, Damage Tolerance TG Mtg., SLC, UT (March, 2015)

Relationships Between Categories of Damage
(using accidental impact damage as an example)

- **Category 1:** More common "small damage", which could be covered by standards (e.g., impactor size/shape, energy cutoffs) if the same limits are ***not*** maintained in moving to Categories 2 and 5.
- **Category 2:** Less common, "more significant damage" that can range in size from the Cat. 1 threshold to larger (bounded by the threats, structural capability and scheduled inspection details, method & interval). Impact standards generally don't exist for this damage and it is likely that a larger, softer impactor can generate damage within visual detection limits (without maintaining Ult. Load); however, taking damage to clearly detectable levels and showing large damage capability (Cat. 3) suggests it's acceptable.
- **Category 3:** Uncommon, large damage that ensures the damage tolerance of the structure without getting into a significant experimental effort on the effects of impactor variables & accidental damage detection.
- **Category 4:** Defined by regulatory event and area of the damage threat
- **Category 5:** Everything else.

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, 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)

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

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**

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 <u>Category 3 and 4 damage</u> and potential mass increase for sandwich panel <u>water ingression</u>
- Emphasized that composite <u>control surfaces</u> may be prone to accidental damage & environmental degradation
- Added words on concerns for a) <u>weight & stiffness changes</u> due to <u>repair</u> or multiple layers of paint and b) structures in proximity of <u>heat sources</u>

Potential Flutter Problems with Minimum Gage Control Surfaces or other "Critical Structures"

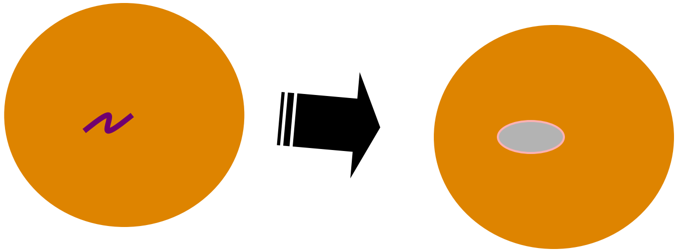
- Lower loads on some control surfaces and large "critical" secondary structures (i.e., residual strength is not in question)
  - Minimum gage structures have individual layers critical to torsion and bending stiffness
  - Layers of safety management needed for continued airworthiness $\Rightarrow$ direct 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)

Blunt Impact of Sandwich Part With Sharp Penetration Near Center



Followed by Poorly Bonded Repair Patch to Penetration Zone Only

Air Transat Flight 961

New CMH-17 Disbond&Delam TG Initiative

Airbus Experience & CMH-17 Task Group for Sandwich Disbond*

CMH-17 COMPOSITE MATERIALS HANDBOOK

Honeycomb Sandwich Disbond Growth Team

- Initiated by Larry Ilcewicz in 2011

Para. 10: Continued Airworthiness

2.5 pages

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

10b. Maintenance Practices, *cont.*

- (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

10b. Maintenance Practices, *cont.*

- (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 (incl. 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

Design for Repair

Early development of maintenance procedures

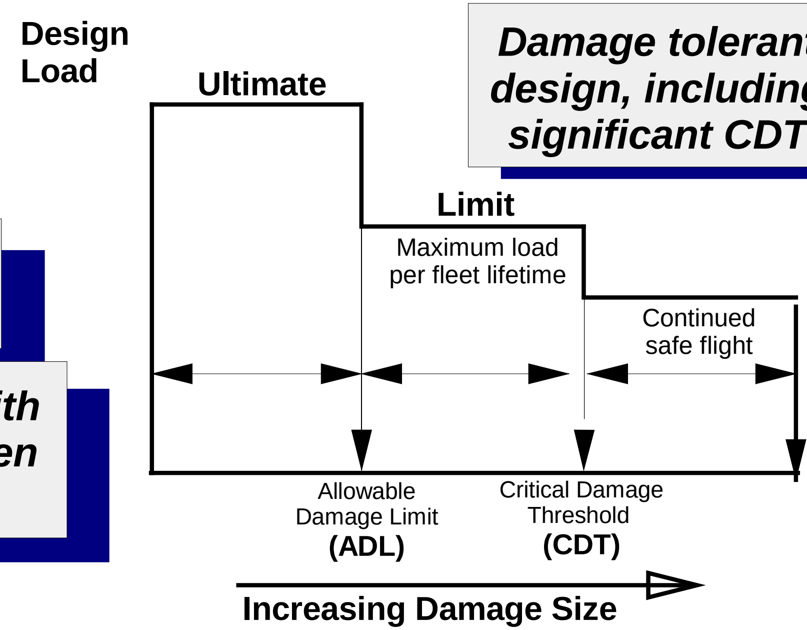
Well-defined ADL

***Efficient, low-cost NDI procedures to locate damage** (that always find CDT)*

Damage tolerant design, including significant CDT

Reliable and simple NDE to quantify effects of damage

Cost-effective repair with minimal down time when damage is found



Taken from: “Composite Technology Development for Commercial Airframe Structures,” L.B. Ilcewicz, Chapter 6.08 from Comprehensive Composites Volume 6,, published by Elsevier Science LTD, 2000.

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

250°F film adhesive well over 6" diameter

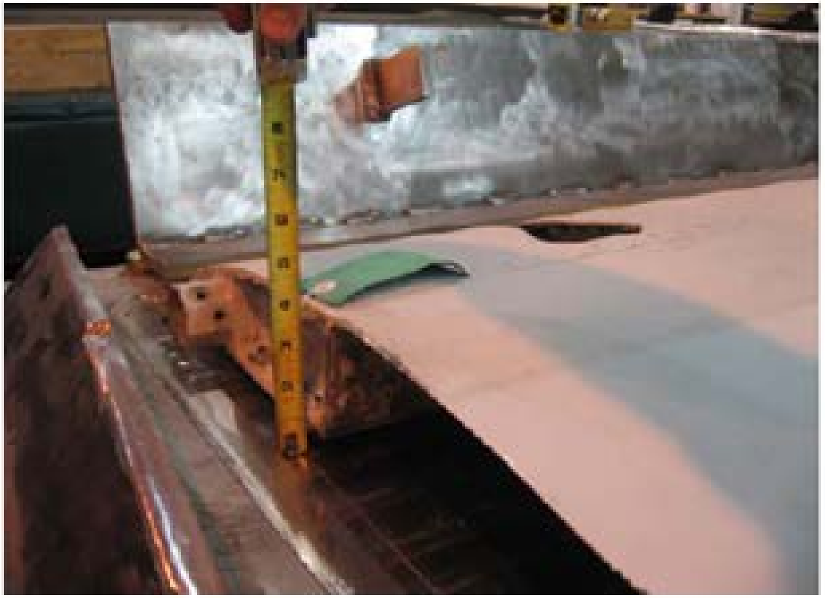
Incorrect film adhesive (SRM limits to 6 inches)

Burn marks on upper skin from overtemping during hot bond repairs.

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

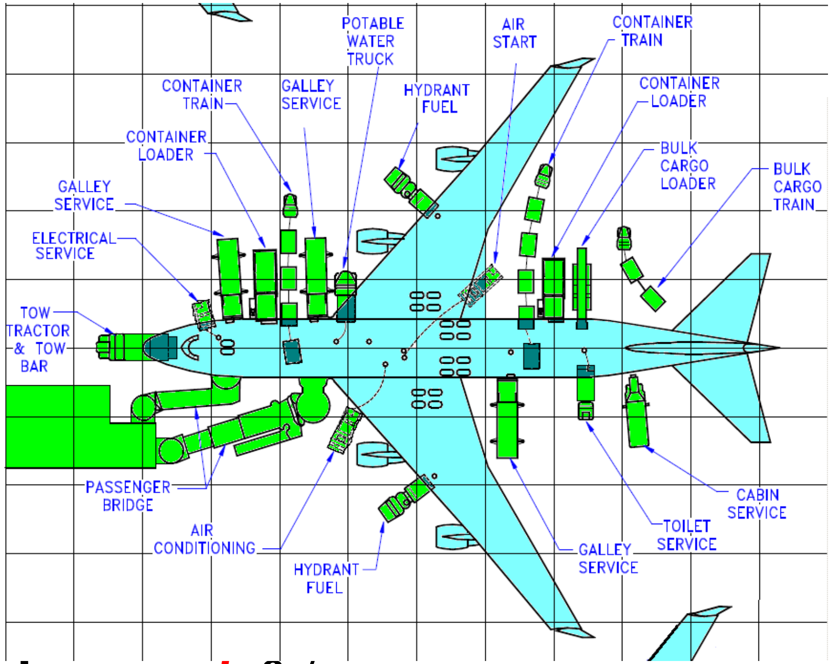
Component	Improper Repair Practices
Flap	**1. Tooling had incorrect contours** **2. Repair outside of SRM limitations** **3. Incorrect hot bonder technique**
Slat	**1. Tooling had incorrect contours** **2. Repair design based on superseded flag note**
Inboard Flap	**1. Repair station did not utilize bond-line confirmation (verifilm) as required by operator engineering** **2. Excessive bond thicknesses suggesting incorrect tool contour** **3. Damaged core from over-heating** **4. Distorted honeycomb replacement core**
Outboard Flap (Metal Bond)	**1. Repair procedure alternative (PAA) utilized instead of HF/Alodine in a procedure which was not approved by the OEM or operator** **2. Improper use of FAA Form 8130-3 approved procedure listing HF/Alodine 'whenever PAA not convenient'**
Nose Cowl	**1. Repair outside of SRM limitations** **2. Improper repair technique and use of materials which appeared to conceal discrepancies**

Reference: "**Nonconforming Composite Repairs: Case Study Analysis",** Charles Seaton and Sarah Richter, Heatcon Composite Training, DOT/FAA/TC-14/20, Nov. 2014

FAA Technical Paper on Awareness & Reporting of Significant Impact Events Involving Composite Airframe Structures

(effort initiated by FAA/EASA/Airbus/Boeing WG)

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://www.youtube.com/v/UFcHUJxQKV4

The Seattle Times

WEDNESDAY
DECEMBER 28, 2005
Metro Edition

...nomish, Island, Kitsap ...nties | 75¢ elsewhere

INDEPENDENT AND LOCALLY OWNED SINCE 1896 | seattletimes.com

"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 thunderous 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 Tuesday.

"This was absolutely terrifying for a few moments," said Hermanns, 28, of Los Angeles. "Basically your ears popped, there's a really loud bang and there wa... lot of white noise. It was li... somebody turned on a leaf blower in your ear."

Though the MD-80 plane was quickly stabilized, he said, passengers spent the next 25 minutes tearful and anxious. An "acrid" odor of burning plastic overwhelmed the cabin. Hermanns ... stunned," said Hermanns, who had been visiting Seattle with his fiancée for Christmas. "It was surreal."

When the 3:54 p.m. flight returned to Seattle-Tacoma International Airport at 4:53 p.m., passengers broke into applause

JEREMY HERMA...
In a photo taken a... plane, Jeremy Her... an oxygen mask.

She said Alaska conducted safety briefings with employees at Sea-Tac on Tuesday "to discuss the importance of rapid and thorough reporting of any ground incidents, whether there is apparent aircraft damage or not."

The airline also is reviewing details from Monday's incident with the NTSB and working with the agency to ensure aircraft safety, she said.

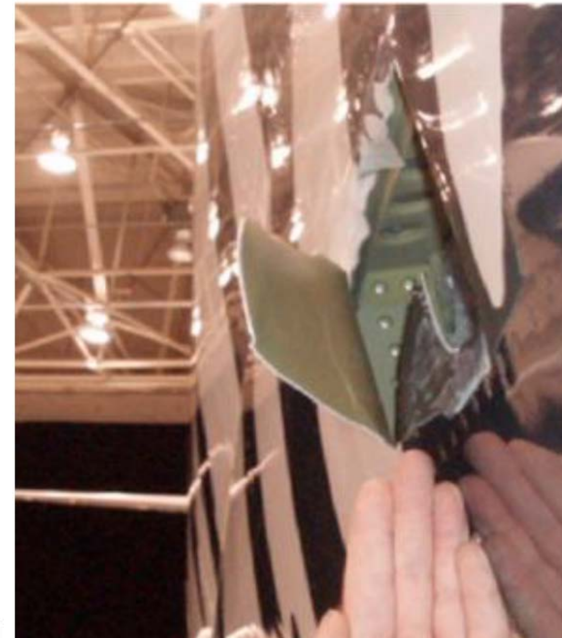


Figure E2: Photo of Skin Failure Following Ground Handling Damage
(photo of 12 in. by 6 in. damage taken after flight depressurization incident)

Taken from ASC-TR-2010-5002
Appendix E: Accidents/ Incidents Resulting From Impact From Ground Equipment

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 needed**
  - Damage resistant structure (to ensure Cat. 5 criteria is met!)
  - Damage tolerance for legitimate Cat. 2 & 3
  - No blame reporting encouraged or mandated
  - Conditional inspection documented
  - Practical NDE to avoid internal access when not practical

Red: Regulatory

Green: Recommendations

- **Provide supporting data on events justified to yield Category 5 damage and the resulting disposition**

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

FAA High Energy Wide Area Blunt Impact Policy

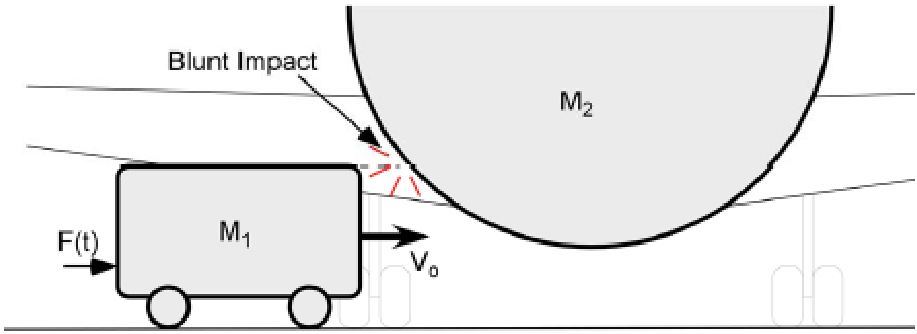
- **Currently completing updates and disposition of public comments for the associated FAA Transport Directorate Policy (Focal: Mark Freisthler)**
- **2015/2016 release schedule**
  - ➢ Public commenting Late September, 2015 to end of 2015
  - ➢ Disposition public comments: January, 2016
  - ➢ Final policy updates: Mid February, 2016
  - ➢ Final issuance: February, 2016
- **Key HEWABI regulatory considerations**
  - – Links to §25.571 (avoid catastrophic failure due to accidental damage, using "other procedures", i.e., reporting/conditional inspections)
  - – Event should be significant to ensure reporting (three criteria for Category 5 damage on previous chart)
  - – Guidance is evolving, with industry experience (B787 and A350)
  - – Future rulemaking will further clarify regulatory basis

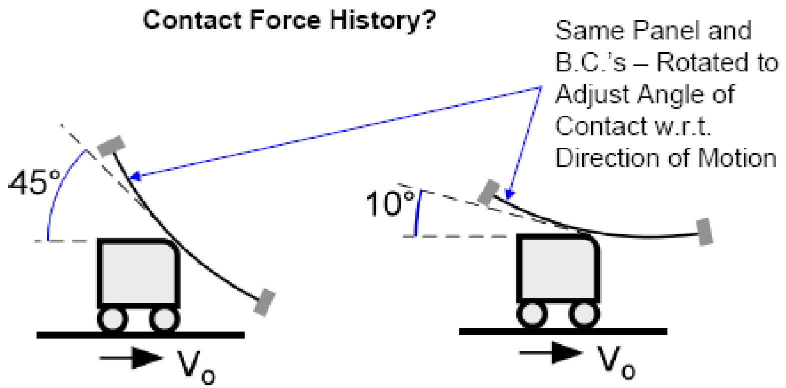
Conditional Inspections and Disposition

- Airworthiness Limitations Section (ALS) of ICA identifies a need for conditional inspections (with possible reference to AMM)
- 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 stiffeners, 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.)

FAA/Industry Research at University of California, San Diego (UCSD)

- **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)



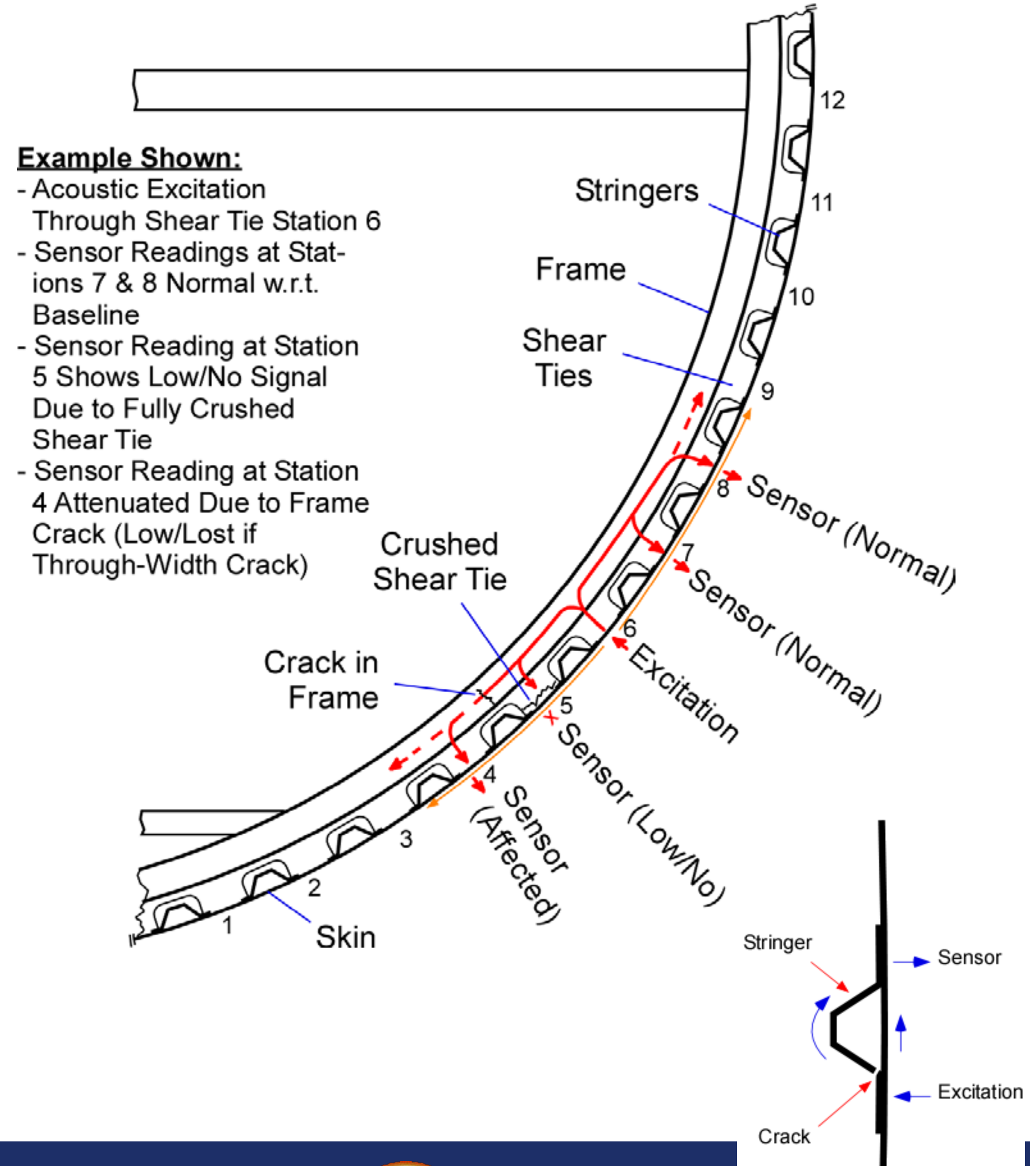


Dr. Hyonny Kim, UCSD

Non Destructive Evaluation of Major Internal Damage

General Approach:

- **pitch-catch guided ultrasonic wave (GUW) approach**
- **structures of interest are form waveguide paths**
- **e.g., *C-frame is like 1D waveguide* – transmission along length affected by damage**
  - excitation from skin side → in through shear tie → travel along frame → out through various shear ties → through skin to sensor
  - broken shear tie and frame will attenuate signal
  - key issues: dominant frequencies associated with waves through frame vs. through skin, many interfaces and complex geometry
- **stringer heel crack – wave propagation through skin and stringer paths**



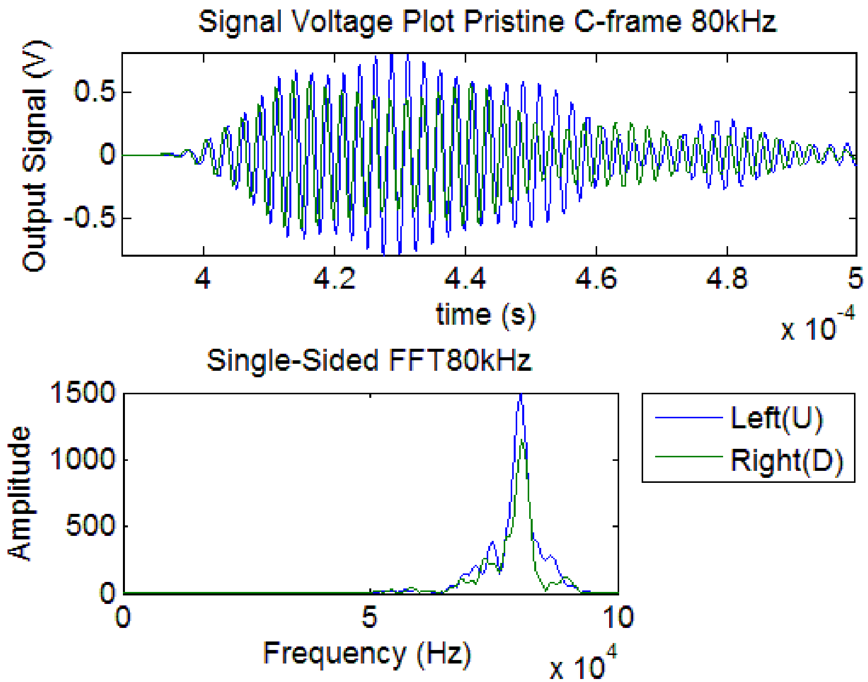
Results: Panel and Frame Initial GUW Tests

Frequency sweep conducted to find dominant frequencies (80 kHz results shown).

Expect: presence of damage → attenuation of signal.

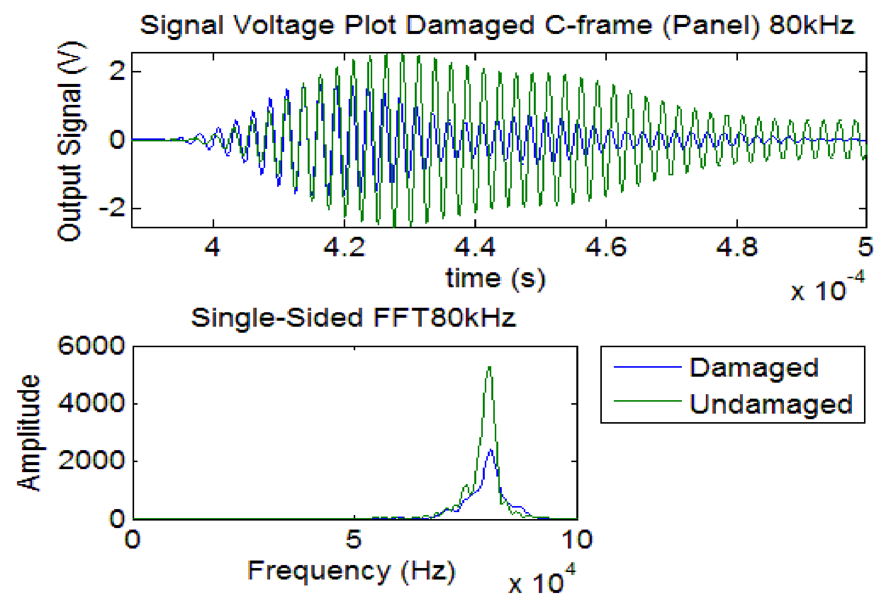
Pristine stand-alone C-frame:

- **small difference measured for left vs. right sensor – due to internal layup/splice effects (needs further investigation)**



Damaged C-frame installed in panel:

- significant attenuation (55%) through damaged path
- cracked C-frame flange detectable for sensors directly mounted to frame – need to test sensing through skin



Future work: (i) account for complex geometry, fasteners, and (ii) more fundamental studies to estimate damage info (mode, size).

Para. 11. Additional Considerations

Content increased from 1.25 to 5 pages

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

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 an industry ARAC WG has been assembled to address the development of new rules and 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

11 b. Fire Protection, Flammability and Thermal Issues, *Cont.*

- 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)

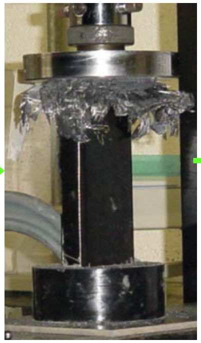
Considerable Differences in Appropriate Regulations for Crashworthiness

Crashworthiness Regulations	Part 23	Part 25	Part 27	Part 29
	561	561	561	561
	562	562	562	562
	601	601	601	601
		631		631
	721	721		
	783	783	783	783
	785	785	785	785
	787	787	787	787
	807	789	801	801
	965	801	807	803
	967	809	965	809
		963		963
		967		967
		981	1413	

XX.562 Seat Rules Derived from Metallic Testing

Certification by Analysis Supported by Test Evidence

•Coupon



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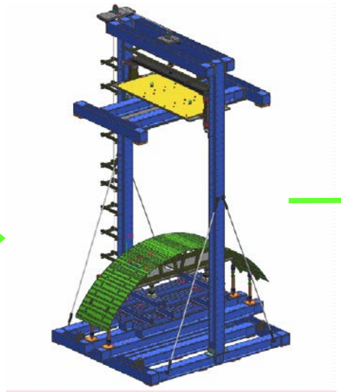

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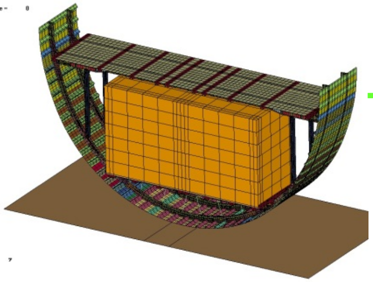
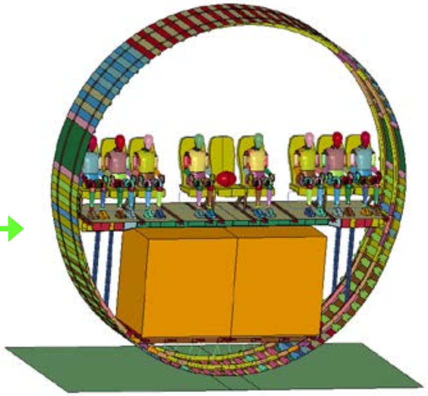


•Large
scale



•Full scale

Analysis Correlation Protocol

•*They are performed at different scales: calibration is allowed at the lower levels of the building block, but only validation is acceptable at higher levels*

- **Coupon level:**
  – Allowables, joints, etc.

•Analysis Definition

- **Element level:**
  – Crush tests of energy absorber or calibration

•Analysis Definition

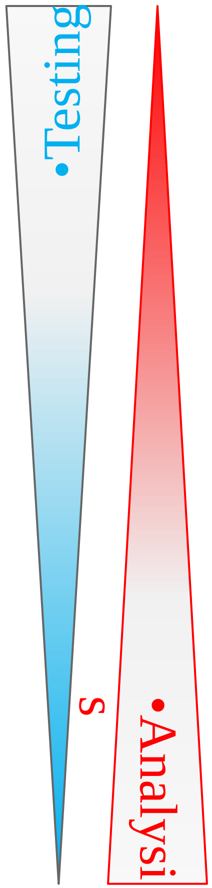
•or Calibration

- **Subcomponent level:**
  – Section of subfloor

•Analysis Calibration

- **Component level:**
  – Subfloor assembly
  – Full-scale barrel section

•Analysis Validation



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 Airplanes)
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

	Part 23	Part 25	Part 27	Part 29
Fire Safety Regulations	609	609	609	609
	787	863	861	861
	863	865	863	863
	867	903	1185	967
	954	967	1191	1013
	1121	1121	1193	1121
	1182	1181	1194	1183
	1183	1182		1185
	1189	1183		1189
	1191	1185		1191
	1193	1189		1193
	1359	1191		1194
	1365	1193		

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. <u>Applicable Regulations</u>
   - "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. <u>Guidance</u>
   - 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

3.5 pages

- 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

AC 20-107C Future Needs and Considerations

(Notes: March 2016 Industry/CAA Meetings, New Zealand)

- **Integrated Product Team considerations**
  - Design/manufacturing integration for technology advances
  - Technology transfer within international teaming relationships
- **Advanced materials & processes maturing over time**
  - Liquid transfer molding processes (e.g., resin infusion, VARTM)
- **Bonded Structure considerations**
  - Wording updates for purposes of clarification (Max Davis inputs)
  - Other failure mode indications of unacceptable "adhesion failures" (e.g., mixed mode failure in metal bonded joints)
  - Bond process scaling issues as related to manufacturing defects
  - Bonded repair substantiation guidelines
- **Composite and bonded structure "damage metrics"**
  - Advances in quantitative NDI (practical, wide area characterization)
  - Health monitoring of critical damage requiring immediate attention

AC 20-107C Future Needs and Considerations

(Notes: March 2016 Industry/CAA Meetings, New Zealand)

- **Safety management aspects of complex problems**
  - Maintenance/Operations training, including “No-blame reporting” programs promoted by many existing airports
  - Application of NDI methods focused on critical structural failures
- **Further guidance for damage threat assessments**
- **Maintenance considerations to promote efficiency**
  - Advances in design/maintenance integration to minimize down time
  - Engineering and technician training standards
- **Advancing shared data for cert. efficiency (e.g., LEF)**
  - Advances for base and repair materials for shared database
- **Continue studying potential aging mechanisms**