Progress on Proof of Structure Module

Tom Walker – NSE Composites
D.M. Hoyt – NSE Composites
Steve Ward – SW Composites

Outline

- Course Outline and Objectives for the Proof of Structure Module

- Detailed Review & Discussions of Fatigue and Damage Tolerance Content

- Open-Discussion

Course Overview

Target Audience:	FAA engineers and Industry ARs
Goal:	Provide sufficient understanding of certification issues and standard practice related to development of composite structure to allow critical assessment of proposed certification plans and approaches
Format:	Primarily web-based, self-paced
Duration:	~80 hrs classroom/lab equivalent

Course Outline

1. Introduction
2. Challenges of Composite Applications
3. Design, Material and Fabrication Development
4. Proof of Structure
5. Quality Control of Composite Manufacturing Processes
6. Maintenance Interface Issues
7. Additional Considerations

- Recently combined “Proof of Structure – Static” and “Proof of Structure – Fatigue & Damage Tolerance” into a single, integrated chapter.
  - Avoids duplicate and/or disconnected discussions
  - Emphasizes the need for an integrated plan to address static and fatigue response for the full spectrum of damages

Course Outline (cont.)

1. Introduction
2. Challenges of Composite Applications
3. Design, Material and Fabrication Development
   - 3.1 Integrated Product Development
   - 3.2 Materials and Process Control
   - 3.3 Composite Structural Design
   - 3.4 Manufacturing Implementation
   - 3.5 Maintenance Considerations
   - 3.6 Statistical Methods
4. Proof of Structure
5. Quality Control of Composite Manufacturing Processes
6. Maintenance Interface Issues
7. Additional Considerations

Includes introductory discussions of several topics addressed more thoroughly in Chapter 4

- *Design requirements and objectives*
- *Damage threat assessment*

Chapter 4 Outline – Proof of Structure

4.1 Related Regulations and Guidance

4.2 Proof of Structure – Static

4.3 Proof of Structure – Fatigue and Damage Tolerance

4.4 Key Concepts

4.5 Compliance Approaches

4.6 Program Development Plan Considerations

4.7 Damage Defects and Inspection

4.8 Design Criteria for Damage and Defects

4.9 Design Considerations for Damage Tolerance

4.10 Damage Threat Assessment

4.11 Repeated-Load Reliability and Load Enhancement Factors

4.12 Building Block Approach

4.13 Full-Scale Testing Considerations

4.14 Inspection Program Definition and Substantiation

Introduction and high-level considerations

Details

Proof of Structure Content Overview (1 of 10)

4.1 Regulations and Guidance

- *Structural requirements related to composite structure, and their sources.*

4.2 Proof of Structure – Static

- *Key issues that must be addressed in demonstrating compliance with static strength requirements.*

4.3 Proof of Structure – Fatigue and Damage Tolerance

- *Key issues that must be addressed in demonstrating compliance with fatigue and damage tolerance requirements.*

4.4 Key Concepts

- *Relationship between Static and Fatigue & Damage Tolerance for metallic and composite structure*
- *Linkage between damage threat assessment, design criteria, and testing*
- *Relationship between damage tolerance and maintenance*
- *Use of load and/or life factors to achieve reliability for repeated loading*

Proof of Structure Content Overview (2 of 10)

4.5 Compliance Approaches

4.5.1 "Test" vs. "Analysis Supported by Test"

- *Key attributes and limitations*
- *Typical usage in demonstrating residual strength and repeated load reliability.*

4.5.2 Deterministic vs. Probabilistic

- *Key concepts and issues*

4.5.3 No Growth vs. Slow Growth vs. Arrested Growth

- *Key aspects of compliance approach options related to damage growth.*

4.6 Program Development Plan Considerations

- *Need for an overall development plan, including schedule and required resources (manpower, facilities)*
- *Contents of certification plan related to Proof of Structures*
- *Relationships between material/processing development and testing, including impact on sequencing*
- *Contents of test plans, test reports, and substantiation documents*

Proof of Structure Content Overview (3 of 10)

4.7 Damage, Defects, and Inspection

- 4.7.1 Sources of damage and manufacturing defects
  - *Defect and damage types associated with manufacturing and service*
- 4.7.2 Complexities of structural impact damage
  - *Complex nature of impact damage in composite structures*
  - *Important variables and trends*
- 4.7.3 Characterizing damage and defects via inspection
  - *Capabilities and limitations of various inspection methods*
  - *Typical usage of inspection methods in the development, production, and service environments*
  - *Implication of limitations to in-service damage strength assessments*

May move some of this content to Prerequisite Module

Proof of Structure Content Overview (4 of 10)

4.8 Design Criteria for Damage and Defects

- *Key objectives for addressing damage and defects in design criteria*
- *Role of probability of detection studies*
- *Current practice for addressing Damage Categories 1-4*
- *Approaches for addressing Category 5 damage*

4.9 Design Considerations for Damage Tolerance

- *Design details and features that can affect robustness and reliability of the aircraft*
- *Examples illustrating importance of considering secondary and/or matrix loading*

Proof of Structure Content Overview (5 of 10)

4.10 Damage Threat Assessment

- *Purpose of a damage threat assessment*
- *Approaches for defining the damage threats.*

4.10.1 Foreign impact damage threats

4.10.2 Load-induced damage threats

4.10.3 Environmental and time-related aging

4.10.4 Discrete source events

4.10.5 Manufacturing defect threats

4.10.6 Case studies on Category 5 damage of safety note

Proof of Structure Content Overview (6 of 10)

4.11 Repeated-Load Reliability and Load Enhancement Factors

- 4.11.1 Reliability Requirements and Objectives
  - *Factors involved in determining reliability*
  - *Selecting reliability levels*
- 4.11.2 Test Spectrum Development
  - *Approaches for developing test fatigue spectrum for composite structure*
  - *Differences between strategies for metallic and composite*
- 4.11.3 LEF Overview
  - *Origin and applicability of LEF = 1.15 "standard"*
  - *Status of current policy*
- 4.11.4 Calculation of LEFs
  - *General concept of calculations*
  - *Key variables and decisions*
- 4.11.5 LEF Testing
  - *Typical test types*
  - *Key considerations in test planning*
- 4.11.6 LEFs for Complex Structure
  - *Considerations for selecting LEFs for tests involving large subcomponents, components, and full-scale articles*

Proof of Structure Content Overview (7 of 10)

4.12 Building Block Approach

- 4.12.1 Introduction to Building Block Approach
  - *Objectives and overall considerations*
- 4.12.2 Structural Design Details
  - *Different details encountered in aircraft design*
- 4.12.3 Design Values Accounting for Material & Process Variability
  - *Issues and considerations in defining tests*
- 4.12.4 Accounting for Environment, Defects, Damage, and Repair
  - *Types of tests for addressing full spectrum of issues*
- 4.12.5 Structural Impact Surveys
  - *Goals and typical critical locations*
- 4.12.6 Typical Test Matrices - Static
  - *Typical matrices at each scale*
- 4.12.7 Typical Test Matrices – F&DT
  - *Typical matrices for Category 2-4 damage and defects*

Proof of Structure Content Overview (8 of 10)

4.12 Building Block Approach (cont.)

- 4.12.8 Static Analysis Correlation with Tests
  - *State-of-the art of analysis for static strength*
  - *Validation considerations*
- 4.12.9 Residual Strength Analysis Correlation with Tests
  - *State-of-the art of analysis for static strength*
  - *Validation considerations*
- 4.12.10 Dealing with “Claims of Advanced Analyses”
  - *Necessity of covering the full design space (e.g., configurations, damage, loading)*
- 4.12.11 Substantiation of Underlining Analysis Assumptions
  - *Addressing real-world design and manufacturing variability and uncertainty*
- 4.12.12 Additional Analyses/Tests to Cover Material/Process Changes
  - *Approaches for addressing range of changes from original design/certification*

Proof of Structure Content Overview (9 of 10)

4.13 Full-Scale Testing Considerations

4.13.1 Considerations for Environmental Effects

- *Key considerations and approaches for addressing effects of environment with RTA test*

4.13.2 Considerations for Non-detectable and Detectable Defects and Damage

- *Approaches and considerations for addressing range of damage and defects in full-scale tests*

4.13.3 Typical Structural Test Setups and Loading

- *Typical setup and loading for a range of major applications*

4.13.4 Typical Structural Test Plans

- *Key contents and considerations*

4.13.5 Test Program Integration

- *Considerations for integrating full-scale Static and F&DT testing for hybrid metal/composites structure*

Proof of Structure Content Overview (10 of 10)

4.14 Inspection Program Definition and Substantiation

4.14.1 Inspection Program Definition

- *The students will describe typical approaches for defining an inspection program.*

4.14.2 Inspection Program Substantiation

- *The students will describe typical considerations and approaches for substantiating an inspection program.*

Discussion

Is the high-level flow reasonable?

Are any key topics missing?

Any questions?

Outline

- Course Outline and Objectives for the Proof of Structure Section

- Detailed Review & Discussions of Fatigue and Damage Tolerance Content

- Open-Discussion

Teaching Techniques

- Primary
  - Slides
  - Expanded discussions in speaker notes
  - Reading assignments w/ key messages and questions
- Augmenting
  - Testimonials
  - Case studies
  - Hands-on Labs?
  - Others?

4.1 Regulations and Guidance

Prepared by:

Date:

Regulations

- **Aircraft Types**
  - Part 23: Normal, Utility, Acrobatic, & Commuter Airplanes
  - Part 25: Transport Airplanes
  - Part 27: Normal Rotorcraft
  - Part 29: Transport Rotorcraft

- **Proof of Structure – Static**
  - §§ 305, 307

- **Proof of Structure – Fatigue & Damage Tolerance**
  - §§ 571, 573

Regulations (cont.)

- **Reading Assignment**
  - 14CFR 25.305, 25.307, 25.571
- **Key Message**
  - Structural regulations are very broad, and provide little or no guidance for how to comply

Guidance

- **FAA Advisory Circulars (ACs) identify an acceptable means of compliance with the regulations**
- **Several ACs are of particular relevance to composite structure**
  - AC 20-107B: Composite Aircraft Structure
  - AC 25.571-1C: Damage Tolerance and Fatigue Evaluation of Structures
  - AC 29-2C MG8: Substantiation of Composite Rotorcraft Structure

Additional discussion in speaker notes

ACs are not requirements, and therefore do not provide the only means of compliance. However, they provide insight into the major concerns that must be addressed during the compliance activity.
AC 20-107B is the primary source of advisory information for composite aircraft structure. It was recently updated (in 2009) and includes the FAAs most recent positions on the full spectrum of compliance issues.

Other Sources of Advice

- **Composites Material Handbook 17 (CMH-17)**
  - Chapter 3: Aircraft Structure Certification & Compliance
  - Chapter 12: Damage Resistance, Durability & Damage Tolerance
  - Chapter 13: Defects, Damage & Inspection
  - Chapter 14: Supportability, Maintenance & Repair

Damage-Related Requirements

- **Reading Assignment**
  - The following Sections in CMH-17, Volume 3
    - 12.1 Introduction, including all subsections
    - 12.2 Rules, Requirements & Compliance For Aircraft
    - 12.2.1 Civil Aviation Regulations and Guidance, including all subsections
- **Key Message**
  - The damage-related requirements can be summarized as shown in the following slides

Summary of Requirements (1 of 3)

1. Structure containing likely damage or defects that are either not detectable or are deemed acceptable during manufacturing inspections and service inspections must withstand Ultimate Load and not impair safe operation of the aircraft for its lifetime (with appropriate factor).

2. Structure containing damage that is detectable and deemed unacceptable during maintenance inspections, but not covered by items 3 and 4 below (i.e., obvious or discrete-source damage), must withstand a once per lifetime (i.e., Limit) load, which is applied following repeated service loads occurring during the applicable inspection interval.

Summary of Requirements (2 of 3)

3. Structure containing damage that will be reliably detected within a few flights of occurrence by operations or ramp maintenance personnel during routine activities (either due to its visibility and location or its obvious influence on the form, fit, or function of the structure), but not covered by item 4 below (i.e., discrete-source damage) must withstand Limit or near-Limit Load.

4. Structure damaged from an in-flight, discrete source that is evident to the flight crew must withstand loads that are consistent with continued safe flight and landing.

Summary of Requirements (3 of 3)

5. All damage that lowers strength below Ultimate Load must be repaired when found.

6. Any damage that is repaired must withstand Ultimate Load and not impair safe operation of the aircraft for its lifetime.

See Word Document with
Chapter 4 Outline Details

Outline

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Damage Tolerance of Repairs

- What are damage/defect scenario requirements for bonded repairs?
  - Process failure? Flaws?
  - Complete departure of bonded repair, etc.?
  - BVID, VID, large notches?
  - Limit load with failed bonded repair (AC 20-107B)

- What are DT issues for bolted repairs?
  - Process failure (drilling, etc.)?
  - BVID, VID, large notches?
  - Thermal loads/stresses for metal repairs to composite structures

- What is current practice?

Multiple vs. Single Load Path Structure

- What defines Multiple Load Path structure?
  - What's needed for a design to be considered Multiple Load Path?
  - Skin-stringer, sandwich, solid laminate with tear straps, etc.
  - Damage arrestment required?

- Is Single Load Path an option for transport category aircraft?
  - Allowed but not best practice?
  - Landing gear vs. fuselage/wing/other structure?
  - If acceptable, what are static implications? (A-basis vs. B-basis allowables)

- Fail safety and/or damage arrestment requirements relative to load path failure, accidental or large damage (Category 3 and 4 damage)

- What are damage tolerance implications?

Environment and Statistical Basis for F&DT

- Large Damage (Categories 2/3/4)
  - What are requirements and/or guidance?
  - Probability of worst-case damage and worst-case location?
  - Also at worst-case environment? Realistic environment?
  - Also apply statistical factor?
  - Probabilistic vs. Deterministic approaches
  - Likely environment at limit load sizing case? Cold?
  - Tension residual strength may be more critical at cold (less “tough”)
- Fatigue/No-Growth
  - What are requirements and/or guidance?
  - Reliability objectives?
  - Add environmental load factor?
  - Appropriate environment for service conditions for specific aircraft or location (e.g., near heat source)
- What is current practice?

Residual Strength After Lightning Strike

- What is current practice regarding design criteria?
- What about damage states resulting from lightning events less severe than the required maximum strike energy?
- Depends on demonstrated detectability?

DT for Different Structural Classifications

- PSE, SSI, Primary, Secondary
  - Principal Structural Element (PSE) per AC25.571-1C
  - Structurally Significant Items (SSI) per MSG-3
  - “Primary” and “Secondary” per colloquial industry use

- Damage tolerance requirements for “Secondary” structure?
  - Requirements vs. customer acceptance / economics?