4.0 Proof of Structure

4.1 Related regulations and guidance

- Students will describe the structural requirements and their sources. Specifically, students will:
  - Identify the specific regulatory paragraphs addressing proof of structure, and describe any major differences in requirements between the different aircraft categories.
    - Categories: Parts 23, 25, 27, and 29
    - Static: §305 and §307
    - Fatigue and Damage Tolerance: §571 and §573
  - Identify relevant regulatory guidance materials and general content
    - AC 20-107B: Composite Aircraft Structures
    - AC 25.571-1D: Damage Tolerance and Fatigue Evaluation of Structures
    - AC 29-2C MG8, "Substantiation of Composite Rotorcraft Structure"
    - AC 23-19A, "Airframe Guide for Certification of Part 23 Airplanes"
    - (Consider including AC 21-26 and/or AC23-20, if relevant)
  - Identify other sources of practical advice
    - CMH-17, Volume 3, Chapters 12 and 13
  - Summarize the damage-related structural requirements
    - 6 items in CMH17 §12.2.1
  - Describe the 5 categories of damage, and their relationship with the structural requirements
    - see CMH17 §12.2.2
  - Discuss the structural classifications of PSE/SSI/Primary/Secondary and the requirement differences between them
  - Discuss the differences between the requirements for metallic structure and those for composite structures (damage, environmental effects, no-growth substantiation)

4.2 Proof of Structures – Static (AC level/content discussion)

- Students will describe the key issues that must be addressed in demonstrating compliance with static strength requirements.

4.3 Proof of Structures – Fatigue & Damage Tolerance (AC level/content discussion)

- Students will describe the key issues that must be addressed in demonstrating compliance with fatigue and damage tolerance requirements.

4.4 Key Concepts

- o Students will identify key factors to consider during the design, analysis, substantiation, and certification of composite structures.

4.4.1 Relationship between Static and F&DT

- o Students will describe the differences in the relationship between Static and F&DT for metallic structures vs. composite structures
    - Metallic: Static addresses pristine strength at Ultimate prior to cyclic loading. F&DT focuses on damage creation and growth from pristine via cyclic loading, and residual strength with that damage.
    - Composites: Static addresses strength with acceptable defects and damage at Ultimate, including cyclic loading. F&DT is largely concerned with demonstrating no/slow/arrested growth of damage from the acceptable defects and damage, and residual strength with that resulting damage.

4.4.2 Key items/goals/objectives for demonstrating compliance (high level, what needs to be done and why)

- o Students will describe the important objectives in demonstrating compliance, and the major steps needed to achieve those objectives.

4.4.3 Linkage between damage threat assessment, design criteria, and testing

- o Students will describe the relationship between the damage threat assessment, the design criteria, and the testing. Specifically, students will:
  - Identify the main goals of a damage threat assessment
    - To identify damage and defect types, locations, and severity levels that may possibly occur in the structure.
  - List the goals of developing damage-related design criteria
    - To specify representative and/or conservative damage and defect types, locations, and severity levels that will be used, for each category of damage, to address those that are identified by the threat assessment.
    - To link the selected damage and defect types/locations/levels to the probability of detection associated with the production and in-service inspection methods.
  - Explain the role of standardized damage in the test program
    - To demonstrate that the structure can meet the necessary loading requirements with the damage and defect types, locations, and severity levels specified in the criteria.

4.4.4 Relationship between damage tolerance and maintenance

- o The students will describe the relationship between damage tolerance and maintenance in ensuring the safety of the aircraft. Specifically, the students will:
  - List the key components and the major goal of the maintenance inspection plan
    - Key components: inspection methods and intervals
    - Primary goal: find damage before it has unacceptably degraded the vehicle safety
  - Explain the major goal of structural repair plan

- Robust repair techniques that reliably restore ultimate strength capability for the duration of the product's life

4.4.5 Repeated-Load Reliability

- Students will describe the use of load and/or life factors to achieve reliability for repeated loading. Specifically, students will:
  - Explain the difference between load and life enhancement factors, and the trade-off between them in demonstrating reliability.
  - Explain the impetus for the use of load factors in lieu of life factors for composites.
    - high scatter, flat S-N curves $\rightarrow$ large life factors (e.g., 11?)
    - load factors needed to make test times practical
  - Identify the major variables associated with developing load and/or life factors.
    - Material
    - Failure mode
  - Compare and contrast this approach for composites with that for metallic structures

Any key issues or content that should be included?

-

4.5 Compliance Approaches

4.5.1 Compliance via "Test" vs. "analysis supported by test"

- The students will describe the major attributes of the "certification by analyses supported by tests" approach, and how it is applied to demonstrate compliance. Specifically, the students will:
  - Explain how analysis methods are validated
  - Describe appropriate criteria for validating stiffness and strength predictions
  - Explain the need for full scale testing for this certification approach (validation of load distribution and stiffness via strain gage and deflection correlation; validation of defects, damages and repairs; validation of critical ultimate load case strength)
  - Explain the selection of the environmental conditions for a full scale tests for this certification approach
  - Describe use of fatigue LEF and # of lifetimes for full scale tests in this certification approach
  - Describe fatigue spectrum and truncation of low loads for full scale tests in this certification approach
  - Describe the types of tests used to validate the "no-growth" of damages and defects with this certification approach
  - Describe how the residual strength of different damage types are accounted for with this certification approach
  - Describe how manufacturing defects are substantiated with this certification approach

- Describe how SRM allowable damages and repairs are substantiated with this certification approach
- Describe what circumstances would allow certification primarily by analysis (e.g., derivative aircraft programs with past data providing sufficient supporting data).
- Note that most aircraft programs that originally certify using analysis supported by tests typically have economic advantages when dealing with real-world problems such as major material, process and other design changes.

o The students will describe the major attributes of the “certification primarily by test” approach, and how it is applied to demonstrate compliance. Specifically, the students will:

- Describe how testing is used in place of analysis in this certification approach to demonstrate compliance with regulatory requirements
- Describe types of full scale tests which are used for this certification approach (wing, fuselage, airplane, horizontal stabilizer, etc)
- Describe typical loading conditions for each full scale test type for this certification approach
- Describe the tradeoffs between testing at room temperature and at hot/cold temperature for full scale tests for this certification approach
- Describe how and when overload factors to account for environmental effects are used for full scale tests for this certification approach
- Describe how and when overload factors to account for material scatter are used for full scale tests for this certification approach
- Describe how different damage types are accounted for in this certification approach
- Describe use of fatigue LEF and # of lifetimes for full scale tests in this certification approach
- Describe fatigue spectrum and truncation of low loads for full scale tests in this certification approach
- Describe the type of coupon tests required when certifying via full scale tests (material specifications, etc)
- Describe the types of tests used to validate the "no-growth" of damages and defects with this certification approach
- Describe how manufacturing defects are substantiated with this certification approach
- Describe how SRM allowable damages and repairs are substantiated with this certification approach

o The students will describe the use of a certification approach that uses a combination of the “by analysis with supporting tests” and the “primarily by test” approaches. Specifically, the students will:

- Explain the need for engineering judgment in addressing proposed approaches that don’t meet expectations for certification by analysis supported by tests.
- Describe how full scale tests are used to validate strength and stiffness predictions with this certification approach
- Describe how full scale tests are used to validate predictions for complex post-buckled structures with this certification approach
- Describe how different damage types are accounted for in this certification approach
- Describe how manufacturing defects are substantiated with this certification approach

- Explain the selection of the environmental conditions for full scale tests for this certification approach
- Describe how SRM allowable damages and repairs are substantiated with this certification approach

- Students will discuss the current typical usage of compliance via "test" and by "analysis supported by test" in demonstrating residual strength and repeated load reliability.
  - Residual strength demonstration: generally via "analysis supported by test"
  - Repeated load reliability: generally demonstrated by test
- Students will discuss the limitations of "test only" approaches (or approaches with limited analysis) in addressing unanticipated manufacturing defects/errors or in-service damage.

4.5.2 Deterministic vs. probabilistic

- Students will describe the key concepts and issues associated with the use of deterministic and probabilistic approaches in certifying composite aircraft structure. Specifically students will:
  - Explain the primary features of the deterministic approach
    - Engineering judgment is used to select conservative event levels, such that the probabilities of occurrence are sufficiently low
  - Explain the primary features of the probabilistic approach
    - Probability distributions are combined to ensure that failure is extremely improbable (taken to be on the order of 10^{-9} per flight hour).
    - Justification for each statistical distribution is required
  - List of the aspects of fatigue and damage tolerance, each of which can be treated either deterministically or probabilistically
    - Damage threats
    - Damage created by the threats
    - Occurrence of loads
    - Growth of damage under repeated loads
    - Static residual strength with damage
    - Detectability of damage with inspection method
    - Frequency of inspections
  - Identify additional sources of information regarding implementation of these approaches
    - CMH-17 §12.2.4, §12.8.2

4.5.3 No Growth vs. Slow Growth vs. Arrested Growth

- Students will describe the compliance approach options related to damage growth. Specifically students will:
  - Explain the three main approaches given in AC20-107B and the type of testing required to support each approach
    - Basic concept of each approaches
    - Slow or arrested growth requires additional testing to characterize growth rates

4.6 Program Development Plan Considerations

- o Students will describe the key considerations related to technical issues, schedules, facilities and human resources in developing an overall aircraft development and certification plan
  - Discuss the need for an overall airplane development plan with a schedule, manpower requirements and required facilities (manufacturing, test, design, and others)
  - Explain the proof-of-structures-related content of a certification plan, and when it should be developed
  - Discuss the linkage of material qualification and allowables/structures test schedules
  - Describe issues with purchases of material batches for qualification and structures tests
  - Describe a typical composite structure test program schedule
  - Explain why the materials and fabrication processes used for the fabrication of all test parts must be representative of those used for the fabrication of the actual airplane components
  - Explain when, in the airplane development schedule, material property data is needed (preliminary sizing, final sizing, MRB, in-factory repair, in-service repair, etc)
- o Students will describe the key contents of test-related certification documents for composite structure. These include:
  - Certification Test Plan
  - Certification test report
- o Students will describe the key contents of substantiation documents for composite structure. These include:
  - static strength
  - damage tolerance
  - fatigue
  - analysis methods
  - allowables and design values
  - SRM allowable damage limits
  - SRM repair strength
  - SRM repair damage tolerance

4.7 Damage, defects, and inspection

4.7.1 Sources of damage and manufacturing defects

- o Students will identify and describe the sources and range of damage and defects that can occur in composite materials. Specifically, the students will:
  - List the major steps of manufacturing composite aircraft parts and the key sources and types of damage associated with each.
    - Manufacturing steps: part fabrication/processing, part transportation/storage, assembly
    - Damage sources: tool drops, machining, assembly, etc
    - Damage types: impact damage, delaminations, etc.
  - List the primary sources and types of damage encountered in the aircraft service environment.

- Damage sources: runway debris, hail, lightning, tool drops, airport equipment/vehicles, discrete source events, etc. (environmental?)
- Damage types: impact damage, scratches/gouges, disbonded elements,

- List the primary sources and types of defects associated with common material forms and manufacturing processes

  - Defect sources: material processing, bonding, repair processing, etc.
  - Defect types: inclusions, porosity, fiber waviness/misalignment, poor bond, porosity, etc.
  - Defect types specific to material forms and processes: gaps (ATL), dry patches (RTM), broken tows (braiding), etc.

4.7.2 Complexities of structural impact damage

- List the main variables affecting the damage resulting from an impact event

  - Impactor: material, shape, mass, energy, velocity, angle of incidence, etc.
  - Material: properties, strengths, form, thickness, manufacturing process
  - Structural Arrangement: effective boundary conditions, elements on opposite side of impact

- Describe the detailed characteristics associated with impact damage

  - Delamination, fiber breakage, matrix cracking, core crush/fracture, remote reactions/damage
  - Conical shape, delaminations linking matrix cracks, etc.

- List some of the important trends related to impact damage, and explain their relationship to the visibility/detectability levels associated with structural criteria

  - Severity vs. energy
  - Visibility vs. energy and thickness
  - Visibility as f(impactor diameter)
  - Dent relaxation over time
  - Non-visible significant damage possible

4.7.3 Characterizing damage and defects via inspection

- o Students will describe typical inspection capabilities and limitations in the development, production, and service environments, as well as the implication of these to in-service damage strength assessments. Specifically, students will:

- Itemize the inspection methods typically available in the production environment, including the damage and defect information that can be obtained by each.

  - TTU:
  - X-ray:

- Itemize the additional inspection methods (including destructive) typically available in the development environment, including the damage and defect information that can be obtained by each.

  - De-ply:
  - Cross-sectioning:

- Thermal imaging:
- CAT scans:

- Itemize the inspection methods typically available in the service environment, including the damage and defect information that can be obtained by each.
  - Visual: depth & planform dimensions of dent or puncture; length, width and depth of surface scratches and gouges
  - Tap test: maximum planform dimensions of delamination, but only for relatively thin laminates
  - Pulse echo: maximum planform dimensions of delamination, possibly disbonding of structural elements on the opposite surface
  - A-scan: Maximum planform dimensions of delamination, depth of delamination closest to surface. possibly disbonding of structural elements on the opposite surface
  - Substantial effort is needed to identify significant damage on opposite surface (removal of interiors prior to visual inspection)
- List the damage characteristics that cannot be identified using typical in-service inspection methods.
  - Extent/location of fiber failure
  - Extent/location of each delamination in a multi-delamination scenario
  - Existence of core damage
  - Kissing bonds
- Describe the shortcomings of practical inspection data relative to predicting residual strength with damage and/or defects.
  - Reductions in stiffness and strength necessary to estimate the effect of the softened zone.
  - Delamination size/shape also needed to assess the effects of sublaminate stability.
- Discuss the importance of developing a link between in-service damage metrics and actual damage state to support residual strength assessments
  - Opportunity exists during development phase to conduct both in-service NDI and intense non-destructive and destructive inspection of representative damage to develop this relationship
- Explain how the roles of NDI in the production and service environments differ
  - Production: Most extensive use of sophisticated NDI. Goal is to ensure that any defects/damages are below specified limits associated with criteria for Ultimate strength through the aircraft's life.
  - In-service: NDI usage is limited. Goal is to understand the extent of damage to support a repair disposition. Typically used only (a) after damage is found, (b) due to a known significant event, or (c) to validate bonded repair quality. Tap-testing most frequent NDI technique. Many sophisticated techniques are not compatible with the maintenance environment (cost, complexity, requirements).

4.8 Design criteria for damage and defects

- Students will describe the role of damage- and defect-related design criteria in achieving aircraft safety. Specifically, the students will:

- List the goals of developing damage-related design criteria
  - To specify representative and/or conservative damage and defect types, locations, and severity levels that will be used, for each category of damage, to address those that are identified by the threat assessment.
  - To link the selected damage and defect types/locations/levels to the probability of detection associated with the production and in-service inspection methods.
- Explain the approach for addressing manufacturing defects in design criteria
  - Identify defect types and sizes associated with material and process specification acceptance limits
  - Criteria must cover common undetectable or acceptable defects in the specifications for no-growth and ultimate load residual strength
  - Criteria should consider rare factory escapements and process failures identified in the damage threat assessment for no-growth and limit load residual strength
- Explain the role of probability of detection studies in setting design criteria
  - Setting severity of BVID and VID such that the damage or defects have a high probability of detection
- Explain current typical industry practice regarding design criteria for Damage Categories 1 through 4.
  - See CMH-17 §12.3.1
- Explain approaches for ensuring safety for Category 5 damage
  - Include design criteria that provide overall robustness.
  - Ensure immediate reporting of severe events via awareness training and a no-blame environment
  - Understand response of aircraft to high energy low velocity impact, including damage created at locations remote to the impact site.
  - Use of AMM comments for rogue events

Any key issues or content that should be included?

4.9 Design Considerations for Damage Tolerance

- Students will describe key design considerations for composite structures that affect fatigue and damage tolerance. Specifically, the students will:

- List structural design details and features that can affect the overall robustness and reliability of the aircraft.
  - From AC20-107B: “Composite damage tolerance and fatigue performance is strongly dependent on structural design details (e.g., skin laminate stacking sequence, stringer or frame spacing, stiffening element attachment details, damage arrestment features, and structural redundancy).”

  - Discuss multi-load path structural design issues

- List some examples that illustrate the importance of considering secondary and/or matrix-direction loads in damage tolerant design

  - Pressure differential across sandwich facesheets: results in cyclic mode 1 loading of any existing facesheet disbonds or core damage.
  - Freeze/thaw of entrapped water: causes cyclic pressure loading of adjacent structure, often resulting in cyclic loading of bondlines or matrix in the vicinity of damage, defects, and/or radii
  - Thermal mismatch of parts (e.g., metallic/composite): results in static and/or cyclic loading
  - Transverse compressive loading combined with interlaminar tension residual stresses: can result in cyclic interlaminar tension loading.
  - Hygrothermal loading combined with residual stresses: can result in cyclic loading of matrix and/or stress increases due to viscoelastic response

> Any key issues or content that should be included?
>
> Ideas for other examples? Stringer runouts? Post-buckled structure? Scaling issues related to testing?

4.10 Damage threat assessment

- Students will explain the purpose of a damage threat assessment and outline approaches for defining the damage threats.

  - Purpose from AC20-107B: "…determine possible locations, types, and sizes of damage considering fatigue, environmental effects, intrinsic flaws, and foreign object impact or other accidental damage (including discrete source) that may occur during manufacture, operation or maintenance."
  - Factors from AC20-107B: "…part function, location on the airplane, past service data, accidental damage threats, environmental exposure, impact damage resistance, durability of assembled structural details (e.g., long-term durability of bolted and bonded joints), adjacent system interface (e.g., potential overheating or other threats associated with system failure), and anomalous service or maintenance handling events that can overload or damage the part."
  - Approach using experience w/ similar aircraft structure/operating environment (fleet survey of telex data), map from metals -> composites … also from references (Russian?)
  - Approach using engineering assessment of vulnerability based on location, geometry and anticipated service environment
  - Damage threats are used to develop design criteria

4.10.1 Foreign object impact damage threats

- Students will list the typical foreign impact damage threats to be included in the damage threat assessment

  - Consider production and service environments
  - Detailed review of possible threats: small tool drop, large tool drop, etc.

4.10.2 Load-induced damage threats

- Students will list the typical load-induced damage threats to be included in the damage threat assessment
    - Overloads, etc.

4.10.3 Environmental and time-related aging

- Students will list the typical environmental and time-related aging damage threats to be included in the damage threat assessment
    - Corrosion – galvanic coupling,
    - Erosion
    - Fluids
    - Thermal/moisture cycling (real-time)
    - UV exposure (and protective finishes)
    - Overheating associated with adjacent system failure

4.10.4 Discrete source events

- Students will list the discrete source damage threats to be included in the damage threat assessment
    - Detailed review of these threats - rotor burst, bird strike, in-flight hail, tire burst, etc.)
    - Include impact by ground vehicles, ground handling equipment, jet gates, runway debris, and thrown tire treads. (CMH-17, §12.3.4)

4.10.5 Manufacturing defect threats

- Students will list the type of defect threats to be included in the damage threat assessment
    - Include potential large defects and process failures that are factory escapements. Small defects are acceptable and let out of factory under the specifications
    - Possible defect threats: bonding process failure leading to partial or complete skin-stringer disbond, missing fasteners, improper assembly (e.g., excessive shimming, large gap pull-up stresses), etc.

4.10.6 Case studies on category 5 damage of safety note

- Large areas of damage that are not easily detected (e.g., weak bonds from improper bonding or repair, large areas of heat damage)

Any key issues or content that should be included?

-

4.11 Repeated-Load Reliability and Load Enhancement Factors

4.11.1 Reliability Requirements and Objectives

- The students will describe repeated-load reliability requirements and objectives and how they are demonstrated via testing
- Explain how repeated-load reliability relates to A-basis, B-basis, and “fatigue reliability factors”

- o Discuss how the fatigue test spectrum, test duration (lifetimes), and LEF combine to generate a level of reliability

4.11.2 Test Spectrum Development

- o The students will describe approaches for developing fatigue test spectra for composite structure.
  - Describe methods for defining simplified test spectra that simulate actual flight spectra (Identifying critical cyclic load cases for defining ground-air-ground cycles)
    - e.g., 5x5 (define actual load cases, define exceedances for each load case, blocking for each load case to simulate exceedance curves)
  - Describe additional modifications necessary for composite structure
    - add high-stress (low-exceedance) flights to achieve near limit load
    - add LEF (may not be appropriate for high-stress flights)
    - Truncating cycles at stress levels below growth threshold
- o The students will compare and contrast truncation/clipping strategies for metallic structure with those for composite structure.

4.11.3 LEF Overview

  - Explain the applicability of the Northrop-developed LEF of 1.15 that is often used in the industry.
  - Explain the need to develop LEFs for each unique combination of material, process, configuration, and failure-mode
  - Explain that official policy for LEF data requirements has yet to be defined
    - Will be developed with the help of industry leaders

4.11.4 Calculation of LEFs

- o The students will describe the calculation of LEFs. Specifically, the student will:
  - Explain the general concepts of the calculations
  - List important considerations and/or decisions involved in the calculation and in the selection of an approach
  - Identify references for detailed calculation of LEFs

4.11.5 LEF Testing

- o The students will describe the data needed to support development of load enhancement factors for composite structure fatigue testing using the building block approach. Specifically, the student will:
  - List the types of failure modes and associated specimens typically included in LEF testing.
  - List some typical considerations when defining detailed test plans for supporting LEF development.
    - Number of specimen replicates
    - Number of material batches
    - Number of load levels
    - Possible inclusion of Category 1 damage and/or defects
    - Possible inclusion of the corresponding static strength tests
    - Possible inclusion of residual strength at runout

4.11.6 LEFs for Complex Structure

- The students will describe approaches for selecting appropriate LEFs for complex structure.
  - Failure modes, etc.

> Any key issues or content that should be included?
>
> What is industry practice regarding selecting the target level of fatigue reliability?
>
> Does the "Test Spectrum Development" represent the approach taken throughout industry? Spectrum modifications for composites?
>
> Current industry practice for evaluating LEF across failure modes?
>
> Current industry practice for selecting a single LEF for full-scale testing with multiple possible failure modes?

4.12 Building block approach

4.12.1 Introduction to Building Block Approach

- The students will describe the major objectives and attributes of a building-block test program. Specifically, the student will:
  - Describe the necessity of aligning the testing with the design criteria and certification approach
  - List the overall goals of building-block testing
    - Address the full spectrum of damage and defects (Categories 1 through 4)
    - Provide data to develop/validate any analysis methods used to demonstrate compliance
    - Provide point-design data to validate configurations and conditions (e.g., loading, environment, damage scenarios) not addressed via analysis.
    - Generate necessary repeated load data to validate no/slow/arrested growth approach
    - Validate selection of representative/conservative damage and defects
    - Generate any data needed as inputs into the analysis methods
    - Generate any data needed to support statistical distributions required by the certification approach
    - Provide substantiation for key loadings and failure modes not addressed in full-scale test (e.g., secondary/matrix loadings)
  - Compare and contrast the building block testing associated with Static and with F&DT
    - Both include damage and defects and have repeated load requirements

    - Severity of defects/damage and number of repeated load cycles differ

- Describe typical types of tests at each test level of the building block
- Describe how analysis is used to link results from different levels
- Describe which test levels are appropriate for different failure modes, material characteristics, damage types, defect types, etc

    - Damage and defects must be addressed at the appropriate scale. Generally, the minimum scale is that which allows appropriate accuracy in damage states and secondary loading, and allows sufficient load redistribution. If a particular aspect is only being addressed at the highest scales, then sufficient background work is needed to ensure that critical cases are being evaluated and all issues are addressed (e.g., material variability).

- Compare and contrast multi-level building block testing vs coupons + full-scale tests

    - multiple load cases
    - critical environments

4.12.2 Structural design details

- Describe the structural design details of different composite structures (see also section 3.3.1; tube, beam, sandwich panel, stiffened panel, shear beam, monocoque laminate, lug/fitting, etc)

4.12.3 Design values accounting for material & process variability

- Describe the different sources of "variability" (random, material, processes, testing, etc)
- Describe the number and types of tests required to assess variability
- Describe the degrees to which coupon/element test articles must be representative of production structure

4.12.4 Accounting for environment, defects, damage, and repair

- Describe types of tests used to characterize effects of environments

- Describe types of tests used to characterize effects of manufacturing defects (wrinkles, porosity, delaminations, resin rich/thin areas, joint tolerances, etc)
- Describe types of tests used to characterize effects of large disbonds
- Describe types of tests used to characterize effects of barely visible impact damage
- Describe types of tests used to characterize effects of clearly visible impact damage
- Describe types of tests used to characterize effects of large notches
- Describe types of tests used to characterize effects of bird strike (and other discrete source damage)

- Describe types of tests used to validate bolted repairs
- Describe types of tests used to validate bonded repairs

4.12.5 Structural impact surveys

- The students will describe the role of impact surveys in the building block program. Specifically, the student will:

    - Itemize typical goals of impact surveys.

    - Assessing damage levels associated with a range of events, to determine critical levels/locations for inclusion in testing
    - Determining appropriate impact event to create desired damage (detectability) for each detail prior to test
    - Generating data associated with dent-relaxation
    - Developing a database linking actual damage to in-service metrics

- List some typical impact locations to consider for skin/stringer and sandwich construction

    - Edge impact vs. surface
    - Stringer CL and flange tip from OML
    - Stringer CL, flange tip, cap flange from IML
    - Top and bottom of core ramp

4.12.6 Typical test matrices - Static

- Describe typical coupon test matrices
- Describe typical element test matrices
- Describe typical subcomponent test matrices
- Describe typical component test matrices

4.12.7 Typical test matrices – F&DT

- The students will describe some examples of typical building-block test matrices addressing F&DT.

    - Large disbond arrestment
    - Fatigue (threshold growth levels and/or growth rates with pre-existing damage)
    - Possibly examples addressing VID, large notch, hail, bird-strike, tire burst, rim release, thrown treads
    - Possibly an example illustrating the need to address severe damage or high loading to help develop engineering database

4.12.8 Static analysis correlation with tests

- The students will describe the state-of-the-art (in the public domain) of analysis methods for predicting key responses related to static capability (in-plane and interlaminar strength, stability, etc.) for each type of structure (see also section 3.3.1; tube, beam, sandwich panel, stiffened panel, shear beam, monocoque laminate, lug/fitting, etc)
- The students will list the necessary aspects to be considered when validating analysis methods with test results for each type of structure (see also section 3.3.1; tube, beam, sandwich panel, stiffened panel, shear beam, monocoque laminate, lug/fitting, etc)

  - Major load paths
  - Secondary loading
  - Failure modes.

4.12.9 Residual strength analysis correlation with tests

- The students will describe the state-of-the-art (in the public domain) of residual strength analysis methods for impact damage, notches, interlaminar, etc.
- The students will list the necessary aspects to be considered when validating analysis methods with test results for configured structure with damage and defects.

- Modified load paths
- Damage initiation and progression
- Final failure load and mode

4.12.10 Dealing with "claims of advanced analyses" (strength predictions vs. full coverage needed to meet requirements)

- Describe regulations that require accurate strength predictions
- Describe criteria for "accuracy" of strength predictions
- Describe what is meant by "design space"
- Describe how analysis methods should be validated across the design space

4.12.11 Substantiation of underlining analysis assumptions (coverage for sources of design & mfg. variability/uncertainties)

- Discuss the as-fabricated material characteristics (material architecture) for laminates, woven preforms, braided preforms, etc
- Explain how to account for differences between analysis geometry and production tolerance variations
- Explain how to account for differences between nominal material (resin content, fiber areal weight, etc) and specification allowable variations

4.12.12 Additional analyses/tests to cover material/process changes (ranging from minor to major)

- Describe different levels of changes
- Describe typical tests to assess each level of change
- Describe types of "surprises" which can occur due to different changes

Any key issues or content that should be included?

Examples of residual strength test matrices (linked to damage type, e.g., impact, notch, etc.)?

Examples of fatigue evaluation test matrices? S-N curves? Truncation levels? LEF? No growth?

Impact survey approaches— relationship and sequencing relative to building block tests?

-

4.13 Full Scale Testing Considerations

4.13.1 Considerations for environmental effects

- The students will describe the key aspects associated with addressing the effects of environment in the full-scale structural tests. Specifically, the students will:
  - Explain why large scale tests are typically conducted at ambient, instead of extreme, environmental conditions
    - Challenges associated with constructing an environmental chamber to both soak and test large structure.

  - The exposure times necessary to achieve equilibrium can be prohibitively long for thick structure.

- Explain two methods for including environmental effects when demonstrating Ultimate strength capability using ambient-environment tests

  - Environmental factors applied to loads
  - Obtain good correlation w/ predictions, then show that the test strains are below the design values for critical environment

- Explain how to determine appropriate overload factors to account for environmental effects
- Discuss how to ensure failure modes are the same between environmental conditions
- Describe interactions between environments and internal loads (particularly for composite-metal hybrid structure)
- Explain typical approaches for addressing environmentally-induced loading in metallic/composite hybrid structure (e.g., thermal mismatch)

  - Address effects in both composite and metallic parts
  - Load factors vs. analytical assessments

4.13.2 Considerations for non-detectable and detectable defects and damage

- Explain how the "quality" of the test article must be representative of production parts in order to capture non-detectable characteristics and material architecture
- Describe how to detect and assess un-intentional defects and damage in the test article
- Discuss how to include intentional defects and damage into the test article
- Itemize the considerations for determining the critical locations for defects and damage

  - High-stress/low-margin locations (per AC25-571C)
  - Critical load paths
  - Locations where the configuration results in severe damage when the detectability of the damage reaches that associated with the damage category being addressed by the particular test

- Itemize typical critical locations for stiffened and sandwich structure

4.13.3 Typical structural test setups and loading

- Describe typical test setup and loading for a GA aircraft wing test
- Describe typical test setup and loading for a transport aircraft wing test
- Describe typical test setup and loading for an unpressurized fuselage test
- Describe typical test setup and loading for a pressurized fuselage test
- Describe typical test setup and loading for a vertical fin test
- Describe typical test setup and loading for a horizontal stabilizer and the differences with a wing test (boundary conditions, etc)

4.13.4 Typical structural test plans

- Describe the outline of a typical full scale test plan
- Describe in detail the contents of a typical full scale test plan and the test objectives

- Describe how instrumentation requirements are linked to the test objectives
- Describe appropriate success criteria for the full-scale test

4.13.5 Test Program Integration

- The students will describe the primary considerations in developing an integrated full-scale test plan addressing the static and F&DT substantiation of hybrid composite/metal structure. Specifically, the students will:
    - Describe the primary certification objectives for the full-scale test program addressing hybrid composite/metal structure.
    - Explain various methods for addressing fatigue for composite/metal hybrids
        - multiple articles
        - variable LEFs to avoid metallic issues
    - Describe the number of large-scale test articles needed, the certification purpose for each, and the rationale against further consolidation
        - Typical practice for new and novel applications
        - Possible changes for applications where there is significant experience with similar materials and structural concepts.
    - Identify typical load-sequencing of full-scale tests and the damage, defects, and repairs associated with each.

> Any key issues or content that should be included?
>
> Further discussion planned for tomorrow…

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4.14 Inspection program definition and substantiation

4.14.1 Inspection program definition

- The students will describe typical approaches for defining an inspection program. Specifically, the student will:
    - Explain the need to consider inspection plans for each damage type
    - Explain the typical usage of visual and NDI techniques
        - Visual – typically for initial detection (economics)
        - NDI – typically used as detailed inspection to characterize damage after initial detection, but sometimes used for initial detection in defect-sensitive areas and/or for hard to detect defects
    - Explain approaches for combining intervals and methods into a complete inspection plan.
        - Deterministic: Environmental and accidental damage ratings (EDR/ADR)
        - Probabilistic: key variables adjusted to meet defined safety level

4.14.2 Inspection program substantiation

- The students will describe typical considerations and approaches for substantiating an inspection program. Specifically, the student will:
  - Explain the need for Probability of Detection (POD) studies to address each inspection method used for initial detection and associated locations
  - Explain the role of POD studies for Category 1 damage in scenarios employing the deterministic and the probabilistic certification approach.
    - Deterministic: only for defining boundary between Category 1 and Category 2 damage. The goal is to have a high probability of detecting damage not covered at Cat 1
    - Probabilistic: probability distributions for full range of Category 1 damage?
  - Explain the need to validate that Category 2 through 4 damage will be detected in the assumed timeframe due to a combination of its obvious nature and the frequency of observation
    - May need a systems study to determine frequency for specific location
    - Example, obvious damage on the lower lobe of the fuselage will be found much more quickly that the same damage on the crown.

Any key issues or content that should be included?

Examples of industry practice for probability of detection (POD) studies?

How is BVID vs. VID level defined?