Perspectives on Fatigue & Damage Tolerance Standardization

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Accommodate Diverse Product Applications

- Category
  - Part 23
    - Normal
    - Commuter
    - Utility
  - Part 25
- Operations
  - Part 91
  - Part 135
  - Part 136
- Operators
  - Private Individuals
  - Corporate
  - Fractional
- Maintenance
  - Company Service Centers
  - Authorized Service Centers
  - FBO’s
  - Lots of others….

Test vs Analysis

- Historical reliance on certification by test.

- Composites challenge the ability and practicality to certify strength solely by full scale test.

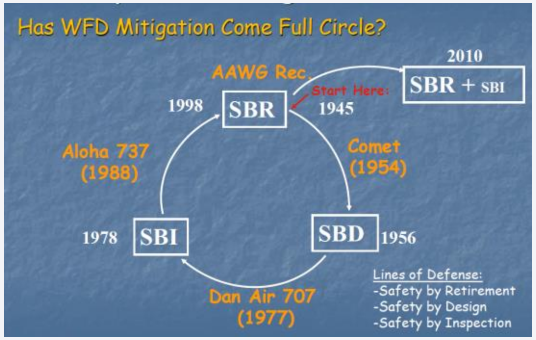
- Significant reliance now on analysis, supported by test.
  - Extensive (and expensive) building block testing
  - FEM/Analysis validations with knockdowns

- Analysis is not considered as good as a test, regardless how well the FEM may be validated.

- Limiting full scale testing as primary means for certification.
  - More reliance on analysis may be increasing risk.
  - Challenge to achieve proper test/analysis balance to maintain historical levels of high confidence.

LOV

- Extensive history of events and evolution and acceptance of rationale for applicability to metals…..still needed for composites



- Applying a metals based requirement to composites
  - Negates fatigue benefits & no growth behavior of composites
  - Need improved understanding of mechanics of damage

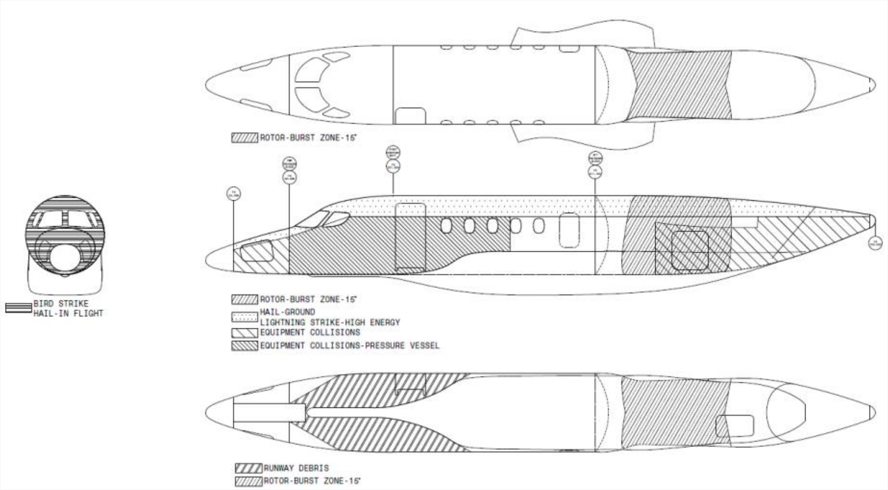
- Likely a non-issue for low utilization GA and corporate owner/operators, which is majority of fleets

- Clarity needed for composites; define “wear-out”.

- Allow for a means to extend composites LOV, comparable to metals?

Threat Assessment

- Limited commonality to (large) transport category airline operational environment
  - Conservative; penalizing



- Differences
  - Exposure areas
  - Types of exposure events
  - Threat sources
  - Scale of structure
  - Scale of (blunt) damage

- Account for differences in maintenance and reporting controls.
  - In general, a much less abusive environment; more controlled.

Damage Criteria

- Maintenance and part acceptance criterion
  - DOT/FAA /AR-96-111 Advanced Certification Methodology for Composite Structures

    6.3.3 Damage Tolerance Design Requirements

    7. No catastrophic structural failure below DUL for structure containing 2.0 inch diameter circular internal damage (detectable by NDI).

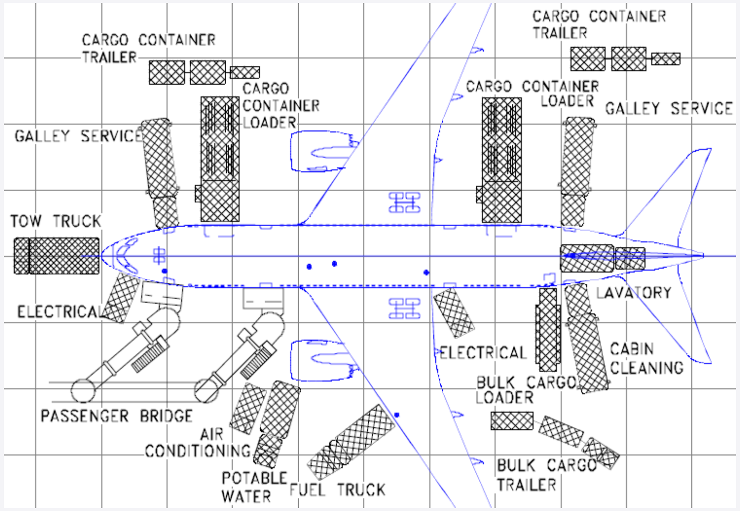
- Environmental testing
  - Saturate at ETW; moisture induces/sets damage
  - Test moisture induced damage at ET but without moisture control

- Category 3 hail damage
  - Thin skin construction more susceptible to hail damage.
  - Hail energy level for Category 3 classification?

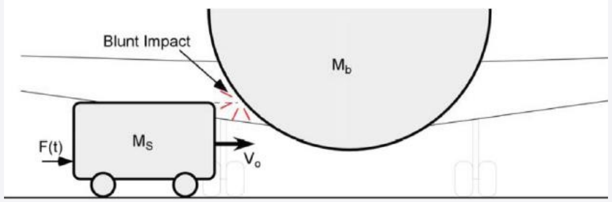
HEWABI

- Part 25 large transport criteria not directly applicable to smaller Part 25 and Part 23.

- Limited commonality to airliner environment
  - Scale of threats
  - Scale of structure
  - Areas of exposure
  - Support operations

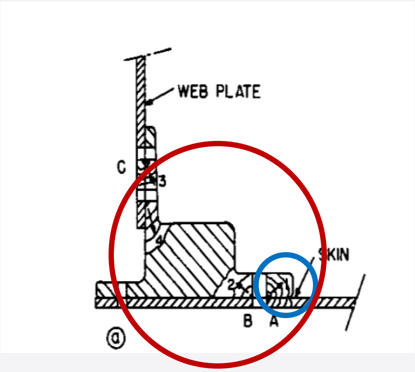


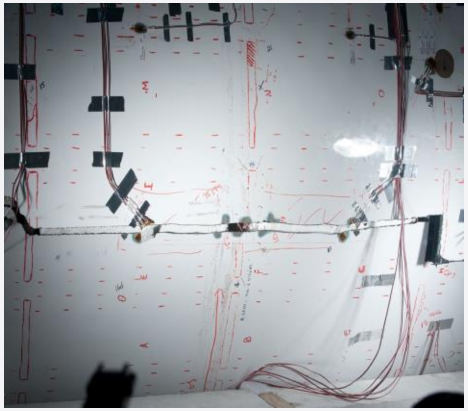
- Alternate basis for exposure environment and criteria:
  - Damage threat assessment
  - Probability based



Large Scale Damage

- What are the criteria for extent of large scale damage?
  - Need practical definition of criteria for composites to achieve large damage sizes.
- 2-Bay damage:
  - Metallic damage source and initiation, propagation and arrestment mechanics are well understood.
  - Conservative to apply a metallic based rationale directly to composites without accounting for damage mechanisms.
    - Rationale damage criteria needed
- Alternate basis:
  - Damage threat assessment to define largest Category 3 (or 4) damage.
  - Residual strength demonstration through full-scale testing.





Material Scatter & Factors

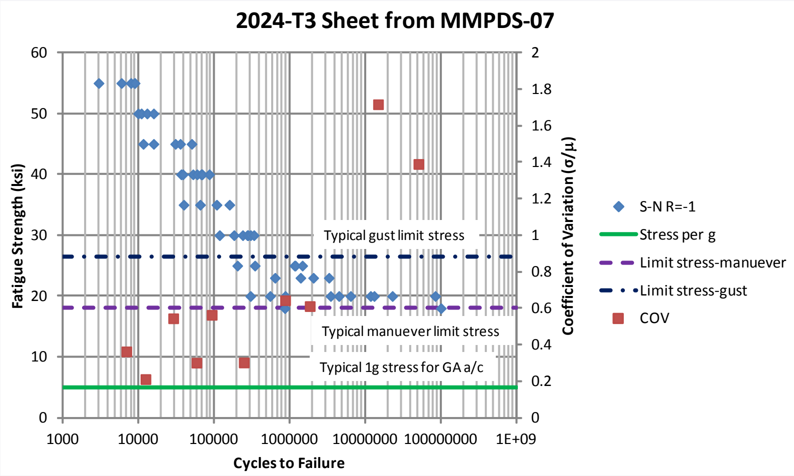
- Metallic
  - A/B basis allowables for static strength
  - Fatigue & damage tolerant allowables use average values
    - Typically no definition of scatter
    - Are environmental variables always consistently applied?

- Composite
  - Fatigue loads approaching static failure levels (e.g., 90%) often necessary to achieve a fatigue failure.
    - Fatigue failure loads are within the static scatter
    - Residual strength greater than static strength
  - Most or all spectrum loads may be below endurance limit
  - Composite truncation could be greater than metallic clipping

Material Scatter & Factors

Beechcraft | Cessna | Hawker
TEXTRON AVIATION

- Load/life enhancement and environment factors
  - Rigorously defined; statistically significant….more than metals?
  - Conservative to apply load and environment factors simultaneously...may not occur at same flight regimes
  - Navy LEF data indicated less scatter in metals than composites
    - Data based on fighter spectrum
    - GA and corporate operates at lower stress levels and load factors
      - » Typically there is greater scatter in material data at lower loads



Sequence Effects?

LEF

- Investigation into a new, different baseline is recommended:
  - Navy data is not viewed as an appropriate baseline
  - Testing to define new baseline
    - Test appropriate metallic materials using spectra representative of GA and small aircraft operational environments
    - Define new scatter parameters

- Test composite materials to spectrum equivalent to metallics and define scatter per standard LEF guidance

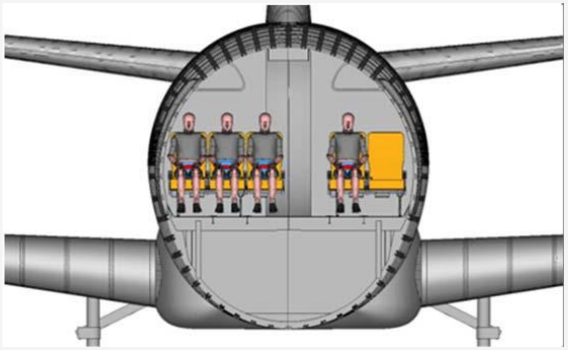
- Compare composite scatter to new baseline metals scatter ==> define GA/small aircraft specific LEF:
  - Adjusting for spectrum effects should reduce load/life factors
  - Reduced unnecessary conservatism
  - Possibly make composites more weight competitive

Crashworthiness

- Part 25 large transport criteria not applicable to smaller Part 25 and Part 23.

- Applying larger airframe standards to smaller class of aircraft may be prohibitively restrictive and penalizing weight.
    - Factor of scale…..weight, size, etc.
    - Maintaining space……smaller volumes
    - Occupant loads…..minimal floor space for energy absorption

VS



Part 23 Rewrite

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TEXTRON AVIATION

FATIGUE EVALUATION

§ 23.571 Metallic pressurized cabin structures.

For normal, utility, and acrobatic category airplanes, the strength, detail design, and fabrication of the metallic structure of the pressure cabin must be evaluated under one of the following:

(a) A fatigue strength investigation in which the structure is shown by tests, or by analysis supported by test evidence, to be able to withstand the repeated loads of variable magnitude expected in service; or

(b) A fail safe strength investigation, in which it is shown by analysis, tests, or both that catastrophic failure of the structure is not probable after fatigue failure, or obvious partial failure, of a principal structural element, and that the remaining structures are able to withstand a static ultimate load factor of 75 percent of the limit load factor at V_C, considering the combined effects of normal operating pressures, expected external aerodynamic pressures, and flight loads. These loads must be multiplied by a factor of 1.15 unless the dynamic effects of failure under static load are otherwise considered.

(c) The damage tolerance evaluation of § 23.573(b).

[Doc. No. 4080, 29 FR 17955, Dec. 18, 1964, as amended by Amdt. 23–14, 38 FR 31821, Nov. 19, 1973; Amdt. 23–45, 58 FR 42163, Aug. 6, 1993; Amdt. 23–48, 61 FR 5147, Feb. 9, 1996]

§ 23.572 Metallic wing, empennage, and associated structures.

(a) For normal, utility, and acrobatic category airplanes, the strength, detail design, and fabrication of those parts of the airframe structure whose failure would be catastrophic must be evaluated under one of the following unless it is shown that the structure, operating stress level, materials and expected uses are comparable, from a fatigue standpoint, to a similar design that has had extensive satisfactory service experience:

(1) A fatigue strength investigation in which the structure is shown by tests, or by analysis supported by test evidence, to be able to withstand the repeated loads of variable magnitude expected in service; or

(2) A fail-safe strength investigation in which it is shown by analysis, tests, or both, that catastrophic failure of the structure is not probable after fatigue failure, or obvious partial failure, of a principal structural element, and that the remaining structure is able to withstand a static ultimate load factor of 75 percent of the critical limit load factor at V_C. These loads must be multiplied by a factor of 1.15 unless the dynamic effects of failure under static load are otherwise considered.

(3) The damage tolerance evaluation of § 23.573(b).

(b) Each evaluation required by this section must—

(1) Include typical loading spectra (e.g. taxi, ground-air-ground cycles, maneuver, gust);

(2) Account for any significant effects due to the mutual influence of aerodynamic surfaces; and

(3) Consider any significant effects from propeller slipstream loading, and buffet from vortex impingements.

[Amdt. 23–7, 34 FR 13090, Aug. 13, 1969, as amended by Amdt. 23–14, 38 FR 31821, Nov. 19, 1973; Amdt. 23–34, 52 FR 1830, Jan. 15, 1987; Amdt. 23–38, 54 FR 39511, Sept. 26, 1989; Amdt. 23–45, 58 FR 42163, Aug. 6, 1993; Amdt. 23–48, 61 FR 5147, Feb. 9, 1996]

§ 23.573 Damage tolerance and fatigue evaluation of structure.

(a) *Composite airframe structure.* Composite airframe structure must be evaluated under this paragraph instead of §§ 23.571 and 23.572. The applicant must evaluate the composite airframe structure, the failure of which would result in catastrophic loss of the airplane, in each wing (including canards, tandem wings, and winglets), empennage, their carrythrough and attaching structure, moveable control surfaces and their attaching structure fuselage, and pressure cabin using the damage-tolerance criteria prescribed in paragraphs (a)(1) through (a)(4) of this section unless shown to be impractical. If the applicant establishes that damage-tolerance criteria is impractical for a particular structure, the structure must be evaluated in accordance with paragraphs (a)(1) and (a)(6) of this section. Where bonded joints are used, the structure must also be evaluated in accordance with paragraph (a)(5) of this section. The effects of material variability and environmental conditions on the strength and durability properties of the composite materials must be accounted for in the evaluations required by this section.

(1) It must be demonstrated by tests, or by analysis supported by tests, that the structure is capable of carrying ultimate load with damage up to the threshold of detectability considering the inspection procedures employed.

(2) The growth rate or no-growth of damage that may occur from fatigue, corrosion, manufacturing flaws or impact damage, under repeated loads expected in service, must be established by tests or analysis supported by tests.

(3) The structure must be shown by residual strength tests, or analysis supported by residual strength tests, to be able to withstand critical limit flight loads, considered as ultimate loads, with the extent of detectable damage consistent with the results of the damage tolerance evaluations. For pressurized cabins, the following loads must be withstood:

(i) Critical limit flight loads with the combined effects of normal operating pressure and expected external aerodynamic pressures.

(ii) The expected external aerodynamic pressures in 1g flight combined with a cabin differential pressure equal to 1.1 times the normal operating differential pressure without any other load.

(4) The damage growth, between initial detectability and the value selected for residual strength demonstrations, factored to obtain inspection intervals, must allow development of an inspection program suitable for application by operation and maintenance personnel.

(5) For any bonded joint, the failure of which would result in catastrophic loss of the airplane, the limit load capacity must be substantiated by one of the following methods—

(i) The maximum disbonds of each bonded joint consistent with the capability to withstand the loads in paragraph (a)(3) of this section must be determined by analysis, tests, or both. Disbonds of each bonded joint greater than this must be prevented by design features; or

(ii) Proof testing must be conducted on each production article that will apply the critical limit design load to each critical bonded joint; or

(iii) Repeatable and reliable non-destructive inspection techniques must be established that ensure the strength of each joint.

(6) Structural components for which the damage tolerance method is shown to be impractical must be shown by component fatigue tests, or analysis supported by tests, to be able to withstand the repeated loads of variable magnitude expected in service. Sufficient component, subcomponent, element, or coupon tests must be done to establish the fatigue scatter factor and the environmental effects. Damage up to the threshold of detectability and ultimate load residual strength capability must be considered in the demonstration.

(b) *Metallic airframe structure.* If the applicant elects to use § 23.571(c) or § 23.572(a)(3), then the damage tolerance evaluation must include a determination of the probable locations and modes of damage due to fatigue, corrosion, or accidental damage. Damage at multiple sites due to fatigue must be included where the design is such that this type of damage can be expected to occur. The evaluation must incorporate repeated load and static analyses supported by test evidence. The extent of damage for residual strength evaluation at any time within the operational life of the airplane must be consistent with the initial detectability and subsequent growth under repeated loads. The residual strength evaluation must show that the remaining structure is able to withstand critical limit flight loads, considered as ultimate, with the extent of detectable damage consistent with the results of the damage tolerance evaluations. For pressurized cabins, the following load must be withstood:

(1) The normal operating differential pressure combined with the expected external aerodynamic pressures applied simultaneously with the flight loading conditions specified in this part, and

(2) The expected external aerodynamic pressures in 1g flight combined with a cabin differential pressure equal to 1.1 times the normal operating differential pressure without any other load.

[Doc. No. 26269, 58 FR 42163, Aug. 6, 1993; 58 FR 51970, Oct. 5, 1993, as amended by Amdt. 23–48, 61 FR 5147, Feb. 9, 1996; 73 FR 19746, Apr. 11, 2008]

§ 23.574 Metallic damage tolerance and fatigue evaluation of commuter category airplanes.

For commuter category airplanes—

(a) *Metallic damage tolerance.* An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, defects, or damage will be avoided throughout the operational life of the airplane. This evaluation must be conducted in accordance with the provisions of § 23.573, except as specified in paragraph (b) of this section, for each part of the structure that could contribute to a catastrophic failure.

(b) *Fatigue (safe-life) evaluation.* Compliance with the damage tolerance requirements of paragraph (a) of this section is not required if the applicant establishes that the application of those requirements is impractical for a particular structure. This structure must be shown, by analysis supported by test evidence, to be able to withstand the repeated loads of variable magnitude expected during its service life without detectable cracks. Appropriate safe-life scatter factors must be applied.

[Doc. No. 27805, 61 FR 5148, Feb. 9, 1996]

§ 23.575 Inspections and other procedures.

Each inspection or other procedure, based on an evaluation required by §§ 23.571, 23.572, 23.573 or 23.574, must be established to prevent catastrophic failure and must be included in the Limitations Section of the Instructions for Continued Airworthiness required by § 23.1529.

[Doc. No. 27805, 61 FR 5148, Feb. 9, 1996]

This may become this

§23.571 Structure durability.

a) Reliable and appropriate procedures must be established to prevent structural failures, due to foreseeable causes of strength degradation, which could result in large reductions in safety margins or functional capabilities, serious or fatal injuries, or loss of the airplane.

b) The airplane must be capable of successfully completing a flight during which likely structural damage occurs due to high-energy fragments from an uncontained engine, motor, or rotating machinery failure.

Part 23 Rewrite: Summary

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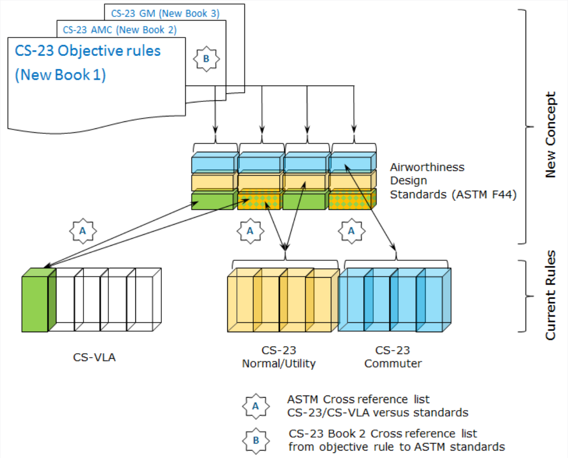
Primary goal: Lower cost of certification without reducing safety.

- Part 23 regulations changed <u>in entirety</u>
  - Prescriptive language removed from rule
  - Only safety aspects retained
- Prescriptive language defined in approved ASTM standards
  - ASTM F44 light aircraft standards based on EASA VLA and glider MOCs….with extensive industry input
  - OEM can create standard(s) for FAA approval
- Much discussion on…
  - Flutter, material allowables, fatigue/DT, design and construction
- Common ground
  - Tiering allows different requirements based on airplane
    - Size, seats, performance…
  - Existing tiering: VLA, normal category, commuter
- Schedule:
  - March 2015 EASA A-NPA 2015-06
  - Fall 2015: FAA NPRM followed by EASA NPA



Part 23 Rewrite:
Composites and the Durability Standard

- Desired: Provide option to eliminate cyclic test requirement.

- Options being discussed:
  - Show that overall airframe stresses are low
    - EASA CS-VLA regulations already allow this
      - Definition of "low stress"? Reference AMC for CS-VLA. Also, fleet data.
    - EASA certifications: no safe life. FAA validations: define a safe life.
  - Enhanced strength test
    - Intent: Ultimate strength testing can demonstrate low airframe stresses
    - No cyclic test if static strength testing at or beyond limit load x 2.0
      - Should enhanced factor be 2.0? For composite, use LEF instead?

Need to start taking into consideration how the rewrite will affect composite standardization efforts, and vice-versa.

Summary

- One size does not fit all.
- Ensure Part 23 and small Part 25 aircraft are not unnecessarily and unfairly burdened by criteria based on large transport category aircraft.
- Equitable requirements while properly accounting for operational environments.
- Awareness of Part 23 rewrite and it's affect.